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IS 2309 : 1989

Indian Standard

PROTECTION OF BUILDINGS AND ALLIED STRUCTURES AGAINST LIGHTNING — CODE OF PRACTICE

(Second Revision)

भारतीय मानक

इमारतों और ऐसी ही अन्य संरचनाओं का बिजली गिरने से बचाव — रीति संहिता

(दूसरा पुनरीक्षण)

UDC 621·316·93 : 699·887·2 : 006·76

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FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards on 29 May 1989, after the draft finalized by the Electrical Installations Sectional Committee had been approved by the Electrotechnical Division Council.

(*Continued on third cover*)

AMENDMENT NO. 1 JANUARY 2006
TO
IS 2309 : 1989 PROTECTION OF BUILDINGS AND ALLIED STRUCTURES AGAINST LIGHTING — CODE OF PRACTICE

(Second Revision)

(*Page* 25, *Fig.* 12, *Key* 10, *Note*) — Delete the NOTE.

(*Page* 46, *clause* **16.2.1**, *Note*) — Add the following at the end of the note:

'The minimum specific criteria is applicable to Mast only.'

(*Page* 47, *Fig.* 31, *Note* 2, *second line*) — Substitute '**12.5.2**' *for* '**15.5.2**'.

(ET 20)

Reprography Unit, BIS, New Delhi, India

Indian Standard

PROTECTION OF BUILDINGS AND ALLIED STRUCTURES AGAINST LIGHTNING — CODE OF PRACTICE

(Second Revision)

1 SCOPE

1.1 This Code outlines the general technical aspects of lightning, illustrating its principal electrical, thermal and mechanical effects. Guidance is given on how to assess the risk of being struck and it offers a method of compiling an index figure as an aid in deciding if a particular structure is in need of protection.

1.2 The Code also offers guidance on good engineering practice and the selection of suitable materials. Recommendations are made for special cases such as explosives stores and temporary structures, for example, cranes, spectator stands constructed of metal scaffolding.

1.3 Where current carrying conductors are directly associated with structures coming within the scope of this Code, certain recommendations relating to them are included; however, the protection of overhead telephone wires, radar stations, electric traction and supply lines should, on account of their special nature, be referred to the specialists.

2 REFERENCES

2.1 The following Indian Standards are necessary adjuncts to this standard:

IS No.	*Title*
IS 732 : 1989	Code of practice for electrical wiring installation (*third revision*)
IS 3043 : 1987	Code of practice for earthing (*first revision*)

SECTION 1 GENERAL AND BASIC CONSIDERATIONS

3 DEFINITIONS

3.0 For the purposes of this Code, the following definitions shall apply.

3.1 Lightning Flash

Electrical discharge of atmospheric origin between cloud and earth comprising one or more impulse of many kiloamps.

3.2 Lightning Strokes

The single distinguishable current impulse of a flash.

3.3 Lightning Protective System

The whole system of conductors used to protect a structure from the effects of lightning.

3.4 Air Termination (Air Termination Network)

That part of a lightning protective system which is intended to intercept lightning discharges.

3.5 Down Conductor

Conductor that connects an air termination with an earth termination.

3.6 Bond

A conductor intended to provide electrical connection between the lightning protective system and other metalwork and between various portions of the latter.

3.7 Joint

A mechanical and/or electrical junction between two or more portions of a lightning protective system.

3.8 Testing Joint

Joints designed and situated so as to enable resistance or continuity measurements to be made.

3.9 Earth Termination (Earth Termination Network)

That part of a lightning protective system which is intended to discharge lightning currents into the general mass of the earth. All points below the lowest testing point in a down conductor are included in this term.

3.10 Earth Electrode

That part of the earth termination making direct electrical contact with earth.

3.11 Ring Conductor

Earth termination or electrode fixed to a structure above or below the earth or within or under foundations. A ring conductor may be used alone as an earth termination network or in conjunction with metal rods as an interconnection conductor.

3.12 Indicating Plate

A plate detailing the number and position of earth electrodes.

3.13 Reference Earth Electrode

An earth electrode capable of being completely isolated from an earth termination network for use in periodic testing.

3.14 Log Book

A record of tests and inspections of a lightning conductor installation.

NOTES

1 The following abbreviations and symbols are used in the illustrations appearing in this standard:

DC — Down conductor
HC — Horizontal conductor
VC — Vertical conductor
ZP — Zone of protection and protective angles

2 The boundary of ZP is indicated by dashed lines.

4 TECHNICAL ASPECTS OF LIGHTNING

4.1 General

Lightning is a natural hazard, being the discharge of static electricity generated in parts, called 'cells', of storm clouds, Some of them damage buildings and a few kill or injure people and animals, either directly or indirectly by causing fire and explosions. Statistics for deaths by lightning show the risk to be very low.

A map showing average number of thunderstorm days in a year in India is given in Fig. 1.

NOTE — The estimation of exposure risk is however worked out in relation to expected number of lightning flashes per square kilometre per year (*see* 8.1.2).

The first step in minimizing the danger from lightning must be to learn as much as possible about its nature. The main characteristics are therefore briefly summarized in 4.2.

4.2 Characteristics of Lightning

4.2.1 *Current in a Lightning Stroke*

Rather than describe an 'average' lightning flash, it is easier to give ranges for the various parameters. The important part of a lightning flash from the resulting damage point of view is the 'return stroke'. This is that part of the flash in which a charged cell in a thunder cloud is discharged to earth. The current in this return stroke ranges from about 2 000 A to about 200 000 A and its distribution of values is of the form which occurs frequently in nature, the so called 'log/normal' distribution. Hence:

1 percent	of strokes	exceed		200 000 A
10 percent	,,	,,	,,	80 000 A
50 percent	,,	,,	,,	28 000 A
90 percent	,,	,,	,,	8 000 A
99 percent	,,	,,	,,	3 000 A

The current in most ground flashes is from the negatively charged cells in the thunder cloud, and the flash current is, therefore, a negative flow from cloud to ground; less frequently, strokes from a positive part of the cloud also occur. For either polarity, however, the current flow is unidirectional with a rise time of less than 10 μs for the negative flash (but considerably longer for the positive flash) and then decays to a low value, for a simple single stroke, in 100 μs or less.

Some flashes comprise two or more strokes which individually conform to the description for a single stroke but which may be spaced in time 50 ms to 100 ms apart. The rare multi-stroke flash having more than 10 strokes may, therefore, last for up to 1 second.

4.2.2 *Voltage*

Before the flash takes place, the potential of the charge cell may be estimated very roughly assuming the charge in the cell to be 100°C and the radius of an equivalent spherical cell to be 1 km. The capacitance of the cell is, therefore, about 10^{-7} F and from $Q = CV$ the potential is estimated to be 10^9 V. It is reasonable, therefore, to assume that the cloud potential is more than 100 MV. This potential is high enough to ensure that the potentials sustained by whatever is struck will be controlled by the product of current and impedance, because this product will never be high enough in comparison with the cloud potential to modify the current magnitude.

Although the return stroke is the most important parameter of a lightning stroke it is necessary to know something of the process which precedes it in order to understand why high structures are more vulnerable than low ones. The lightning stroke starts by the step by step descent from the cloud of a leader stroke stepping some tens of metres at a time. When the last step brings the tip of the leader sufficiently close to earth, an upward streamer leaves the earth to join the tip of downward leader.

The initiation of this upward streamer depends on a critical field being exceeded at the earth emission point and so is a function of the charge deposited by the down-coming leader and any enhancement of the field caused by the geometry of the earth. The length of the upward streamer will be greater for greater charges and hence high current flashes will start preferentially from high structures for which the field enhancement is high.

5 EFFECTS OF LIGHTNING STROKE

5.1 Electrical Effects

As the current is discharged through the resistance of the earth electrode of the lightning protective system, it produces a resistive voltage drop which may momentarily raise the potential of the protective system to a high value relative to true earth. It may also produce around the earth electrodes a high potential gradient dangerous to persons and animals. In the same general manner, the inductance of the protective system must also be considered because of the steep leading edge of the lightning pulse.

The resulting voltage drop in the protective system is, therefore, the combination of the resistive and inductive voltage components.

5.2 Side Flashing

The point of strike on the protective system may be raised to a high potential with respect to adjacent metal. There is, therefore, a risk of flashover from the protective system to any other metal on or in the structure. If such flashover occurs, part of the lightning current is discharged through internal installations, such as pipes and wiring, and so this flashover constitutes a risk to the occupants and fabric of the structure.

5.3 Thermal

As far as it affects lightning protection, the effects of a lightning discharge is confined to the temperature rise of the conductor through which the current passes. Although the current is high, its duration is short, and the thermal effect on the protective system is usually negligible. (This ignores the fusing or welding effects on damaged conductors or those which were not adequate in the initial installation.) In general, the cross-sectional area of a lightning conductor is chosen primarily to satisfy the requirements of mechanical strength, which means that it is large enough to keep the rise in temperature to 1°C. For example, with a copper conductor of 50 mm^2 cross section, a severe stroke of 100 kA with a duration of 100 μs dissipates less than 400 J per metre of conductor resulting in a temperature rise of about 1°C. The substitution of steel for copper results in a rise of less than 10°C.

5.4 Mechanical Effects

Where a high current is discharged along parallel conductors at close proximity, or along a single conductor with sharp bends, considerable mechanical forces are produced. Secure mechanical fittings are, therefore, essential.

A different mechanical effect exerted by a lightning flash is due to the sudden rise in air temperature to 30 000 K and the resulting explosive expansion of the adjacent air in the channel along which the charge is propagated. This is because, when the conductivity of the metal is replaced by that of an arc path, the energy increases about one hundredfold. A peak power of about 100 MW/m can be attained in the return stroke and the shock wave close to this stroke readily dislodges tiles from a roof.

Similarly, with a secondary flash inside the building, the shock wave can result in damage to the building fabric.

6 FUNCTION OF A LIGHTNING CONDUCTOR

6.1 A lightning conductor is incapable of discharging a thunder cloud without a lightning stroke. Its function is to divert to itself a lightning discharge which might otherwise strike a vulnerable part of the structure to be protected. The range over which a lightning conductor can attract a lightning stroke is not constant, but it is now believed to be a function of the severity of the discharge. The range of attraction is, therefore, a statistical quantity.

On the other hand, the range of attraction is little affected by the configuration of the conductor, so that vertical and horizontal arrangements are equivalent. The use of pointed air terminations or vertical finials is, therefore, not regarded as essential except where dictated by practical considerations.

7 OTHER METHODS OF LIGHTNING PROTECTION

7.1 This code considers 'conventional' lightning protective systems. Attention has been given to methods intended to increase artificially the range of attraction afforded by an air termination, as well as a system aimed at reducing the likelihood of an actual discharge.

NOTE — Additional guidelines covering these are under consideration.

8 BASIC CONSIDERATIONS FOR PROTECTION

8.0 Introduction

Before proceeding with the detailed design of a lightning protective system, the following essential steps should be taken:

a) Decide whether or not the structure needs protection and, if so, what are the special requirements (*see* **8.1** and **8.2**).

b) Ensure a close liaison between the architect, the builder, the lightning protective system engineer, and the appropriate authorities throughout the design stages.

c) Agree the procedures for testing, commissioning and future maintenance.

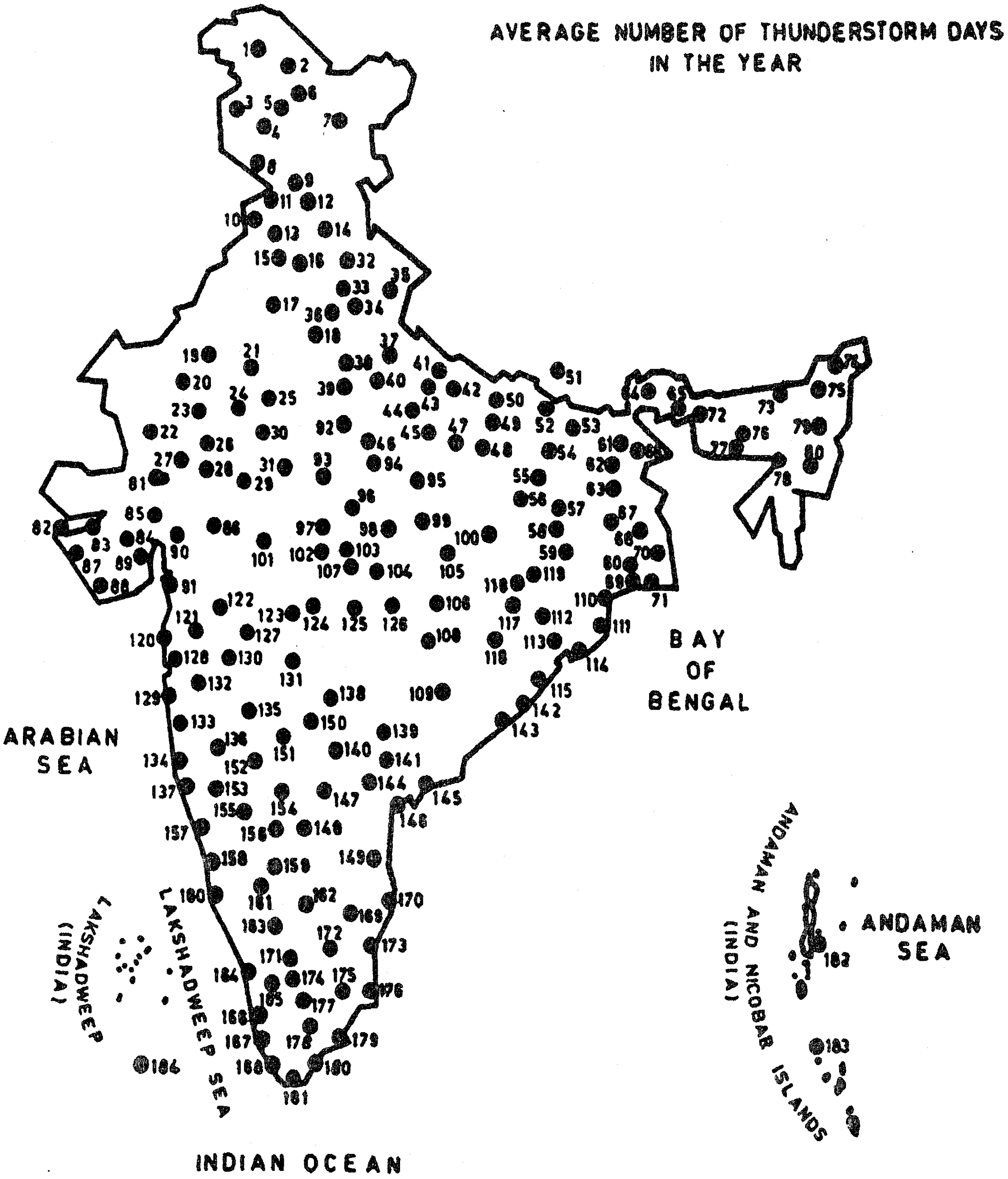

AVERAGE NUMBER OF THUNDERSTORM DAYS IN THE YEAR
ARABIAN SEA
BAY OF BENGAL
LAKSHADWEEP (INDIA)
LAKSHADWEEP SEA
ANDAMAN AND NICOBAR ISLANDS (INDIA)
ANDAMAN SEA
INDIAN OCEAN

FIG. 1

NOTES ACCOMPANYING FIGURE 1

Sl No.	*Name of Place*	*Annual Thunder-Storm Days*
1.	Chloht	7
2.	Skarou	5
3.	Gulmarg	53
4.	Srinagar	54
5.	Dras	3
6.	Kargil	2
7.	Leh	3
8.	Jammu	26
9.	Dharamsala	13
10.	Amritsar	49
11.	Pathankot	4
12.	Mahoi	46
13.	Ludhiana	12
14.	Shimla	40
15.	Patiala	26
16.	Ambala	9
17.	Hissar	27
18.	Delhi	30
19.	Bikaner	10
20.	Phalodi	14
21.	Sikar	17
22.	Barmer	12
23.	Jodhpur	23
24.	Ajmer	26
25.	Jaipur	39
26.	Kankroli	36
27.	Mount Abu	4
28.	Udaipur	34
29.	Neemuch	23
30.	Kota	27
31.	Jhalawar	40
32.	Mussoorie	61
33.	Roorkee	76
34.	Moradabad	36
35.	Mukteshwar	53
36.	Meerut	—
37.	Bareilly	34
38.	Aligarh	30
39.	Agra	24
40.	Mainpuri	23
41.	Bharaich	31
42.	Gonda	22
43.	Lucknow	10
44.	Kanpur	26
45.	Fetehpur	24
46.	Jhansi	20
47.	Allahabad	51
48.	Varanasi	51
49.	Azamgarh	1
50.	Gorakhpur	11
51.	Kathmandu	74
52.	Muthihari	38
53.	Darbhanga	10
54.	Patna	33
55.	Gaya	38
56.	Daltonganj	73
57.	Hazaribagh	73
58.	Ranchi	34
59.	Chaibasa	74
60.	Jamshedpur	66
61.	Purnea	52
62.	Sabour	76
63.	Dumka	63
64.	Darjeeling	20
65.	Jalpaiguri	68
66.	Malda	50
67.	Asansol	71
68.	Burdwan	33
69.	Kharagpur	76
70.	Calcutta	70
71.	Sagar Island	41
72.	Dhubri	8
73.	Tezpur	27
74.	Dibrugarh	70
75.	Sibsagar	103
76.	Shillong	75
77.	Cheerapunji	49
78.	Silchar	33
79.	Kohnia	34
80.	Imphal	49
81.	Deesa	7
82.	Dwarka	5
83.	Jamnagar	6
84.	Rajkot	12
85.	Ahmadabad	11
86.	Dohad	17
87.	Porbandar	3
88.	Verawal	3
89.	Bhavnagar	11
90.	Vadodara	8
91.	Surat	4
92.	Gwalior	53
93.	Guna	33
94.	Nowgong	59
95.	Satna	41
96.	Sagar	36
97.	Bhopal	44
98.	Jabalpur	50
99.	Umaria	37
100.	Ambikapur	29
101.	Indore	34
102.	Hoshangabad	37
103.	Pachmarhi	30
104.	Seoni	51
105.	Penda Dam	56
106.	Rajpur	34
107.	Chindwara	27
108.	Kanker	37
109.	Jagdalpur	38
110.	Balasore	81
111.	Chandbali	75
112.	Angul	81
113.	Bhubaneshwar	46
114.	Puri	33
115.	Gopalpur	34
116.	Sambalpur	67
117.	Jharsuguda	85
118.	Titlagarh	24
119.	Rajgangpur	1
120.	Damamu	4
121.	Nasik	17
122.	Malegaon	13
123.	Akola	20
124.	Khraoti	32
125.	Nagpur	45
126.	Gonda	10
127.	Aurangabad	36
128.	Bombay	18
129.	Alibag	12
130.	Ahmednagar	10
131.	Parbhani	32
132.	Pune	22
133.	Mahabaleshwar	14
134.	Ratnagiri	6
135.	Sholapur	23
136.	Miraj	25
137.	Vengurla	39
138.	Nizamabad	36
139.	Hanamkonda	43
140.	Hyderabad	28
141.	Khammam	26
142.	Kalingapatnam	26
143.	Vishakapatnam	20
144.	Rentichintala	47
145.	Machhilipatnam	20
146.	Ongole	25
147.	Kurnool	29
148.	Anantapur	27
149.	Nellore	18
150.	Bidar	16
151.	Gulbarga	34
152.	Bijapur	9
153.	Belgaum	31
154.	Raichur	17
155.	Gadag	21
156.	Bellari	22
157.	Karwar	27
158.	Honawar	5
159.	Chikalthana	24
160.	Mangalore	36
161.	Hassan	76
162.	Bangalore	45
163.	Mysore	44
164.	Hozhmoode	39
165.	Palghat	35
166.	Cochin	63
167.	Allepey	57
168.	Trivandrum	48
169.	Vellore	25
170.	Madras	47
171.	Ootacamund	24
172.	Salem	65
173.	Cuddalore	37
174.	Coimbatore	40
175.	Tiruchirapalli	41
176.	Nagapattinam	15
177.	Kodaikanal	82
178.	Madurai	39
179.	Pamban	5
180.	Tuticorin	14
181.	Kanyakumari	60
182.	Port Blair	62
183.	Car Nicobar I	10
184.	Minicoy	20

8.1 Need for Protection

8.1.1 *General*

Structures with inherent explosive risks; for example, explosives factories, stores and dumps and fuel tanks; usually need the highest possible class of lightning protective system and recommendations for protecting such structures are given in **15** and **16**.

For all other structures, the standard of protection recommended in the remainder of the Code is applicable and the only question remaining is whether to protect or not.

In many cases, the need for protection may be self-evident, for example:

- where large numbers of people congregate;
- where essential public services are concerned;
- where the area is one in which lightning strokes are prevalent;
- where there are very tall or isolated structures;
- where there are structures of historic or cultural importance.

However, there are many cases for which a decision is not so easy to make. Various factors effecting the risk of being struck and the consequential effects of a stroke in these cases are discussed in **8.1.2** to **8.1.8**.

It must be understood, however, that some factors cannot be assessed, and these may override all other considerations. For example, a desire that there should be no avoidable risk to life or that the occupants of a building should always feel safe, may decide the question in favour of protection, even though it would normally be accepted that there was no need. No guidance can be given in such matters, but an assessment can be made taking account of the exposure risk (that is the risk of the structure being struck) and the following factors:

a) Use to which the structure is put,
b) Nature of its construction,
c) Value of its contents or consequential effects,
d) The location of the structure, and
e) The height of the structure (in the case of composite structures the overall height).

8.1.2 *Estimation of Exposure Risk*

The probability of a structure or building being struck by lightning in any one year is the product of the 'lightning flash density' and the 'effective collection area' of the structure. The lightning flash density, N_g, is the number of (flashes to ground) per km² per year.

NOTE — For the purposes of this Code, the information given in Fig. 1 on thunderstorm days per year would be necessary to be translated in terms of estimated average annual density N_g. The table below which indicates the relationship between thunderstorm days per year and lightning flashes per square kilometre per year:

Thunderstorm days/year	*Lightning Flashes per km² per Year*	
	Mean	Limits
5	0·2	0·1 -0·5
10	0·5	0·15-1
20	1·1	0·3-3
30	1·9	0·6-5
40	2·8	0·8-8
50	3·7	1·2-10
60	4·7	1·8-12
80	6·9	3-17
100	9·2	4-20

The effective collection area of a structure is the area on the plan of the structure extended in all directions to take account of its height. The edge of the effective collection area is displaced from the edge of the structure by an amount equal to the height of the structure at that point. Hence, for a simple rectangular building of length L, width W and height H metres, the collection area has length ($L + 2H$) metres and width ($W + 2H$) metres with four rounded corners formed by quarter circles of radius H metres. This gives a collection area, A_0 (in m²) of (*see* **12.5.2.2**):

$$A_0 = (L \times W) + 2 (L \times H) + 2 (W \times H) + \pi H^2 \quad \ldots \quad \ldots \quad (1)$$

The probable number of strikes (risk) to the structure per year is:

$$P = A_0 \times N_g \times 10^{-6} \quad \ldots \quad \ldots \quad \ldots (2)$$

It must first be decided whether this risk P is acceptable or whether some measure of protection is thought necessary.

8.1.3 *Suggested Acceptable Risk*

For the purposes of this Code, the acceptable risk figure has been taken as 10^{-5}, that is, 1 in 100 000 per year.

8.1.4 *Overall Assessment of Risk*

Having established the value of P, the probable number of strikes to the structure per year [*see* equation (2) in **8.1.2**] the next step is to apply the 'weighting factors' in Tables 1 and 2.

This is done by multiplying P by the appropriate factors to see whether the result, the overall weighting factors, exceeds the acceptable risk of $P = 10^{-5}$ per year.

8.1.5 *Weighting Factors*

In Tables 1A to 1E, the weighting factor values are given under headings 'A' to 'E,' denoting a relative degree of importance or risk in each case. The tables are mostly self-explanatory but it may be helpful to say something about the intention of Table 1C.

The effect of the value of the contents of a structure is clear: the term 'consequential effect' is intended to cover not only material risks to goods and property but also such aspects as the disruption of essential services of all kinds, particularly in hospitals.

The risk to life is generally very small, but if a building is struck, fire or panic can naturally result. All possible steps should, therefore, be taken to reduce these effects, especially among childern, the old, and the sick.

Table 1 Overall Assessment of Risk

(*Clauses* 8.1.4 *and* 8.1.5)

Table 1A Weighting Factor 'A' (Use of Structure)

Use to Which Structure is Put	Value of 'A'
Houses and other buildings of comparable size	0·3
Houses and other buildings of comparable size with outside aerial	0·7
Factories, workshops and laboratories	1·0
Office blocks, hotels, blocks of flats and other residential buildings other than those included below	1·2
Places of assembly, for example, churches, halls, theatres, museums, exhibitions, departmental stores, post offices, stations, airports, and stadium structures	1·3
Schools, hospitals, children's and other homes	1·7

Table 1B Weighting Factor 'B' (Type of Construction)

Type of Construction	Value of 'B'
Steel framed encased with any roof other than metal*	0·2
Reinforced concrete with any roof other than metal	0·4
Steel framed encased or reinforced concrete with metal roof	0·8
Brick, plain concrete or masonry with any roof other than metal or thatch	1·0
Timber framed or clad with any roof other than metal or thatch	1·4
Brick, plain concrete, masonry, timber framed but with metal roofing	1·7
Any building with a thatched roof	2·0

*A structure of exposed metal which is continuous down to ground level is excluded from these tables as it requires no lightning protection beyond adequate earthing arrangements.

Table 1C Weighting Factor 'C' (Contents or Consequential Effects)

Contents or Consequential Effects	Value of 'C'
Ordinary domestic or office buildings, factories and workshops not containing valuable or specially susceptible contents	0·3
Industrial and agricultural buildings with specially susceptible* contents	0·8
Power stations, gas works, telephone exchanges, radio stations	1·0
Industrial key plants, ancient monuments and historic buildings, museums, art galleries or other buildings with specially valuable contents	1·3
Schools, hospitals, children's and other homes, places of assembly	1·7

*This means specially valuable plant or materials vulnerable to fire or the results of fire.

Table 1D Weighting Factor 'D' (Degree of Isolation)

Degree of Isolation	Value of 'D'
Structure located in a large area of structures or trees of the same or greater height, for example, in a large town or forest	0·4
Structure located in an area with few other structures or trees of similar height	1·0
Structure completely isolated or exceeding at least twice the height of surrounding structures or trees	2·0

Table 1E Weighting Factor 'E' (Type of Country)

Type of Country	Value of 'E'
Flat country at any level	0·3
Hill country	1·0
Mountain country between 300 m and 900 m	1·3
Mountain country above 900 m	1·7

8.1.6 *Interpretation of Overall Risk Factor*

The risk factor method put forward here is to be taken as giving guidance on what might, in some cases, be a difficult problem. If the result obtained is considerably less than 10^{-5} (1 in 100 000) then, in the absence of other overriding considerations, protection does not appear necessary; if the result is greater than 10^{-5}, say for example 10^{-4} (1 in 10 000) then sound reasons would be needed to support a decision not to give protection.

When it is thought that the consequential effects will be small and that the effect of a lightning stroke will most probably be merely slight damage to the fabric of the structure, it may be economic not to incur the cost of protection but to accept the risk. Even though, this decision is made, it is suggested that the calculation is still worthwhile as giving some idea of the magnitude of the calculated risk being taken.

8.1.7 *Anomalies*

Structures are so varied that any method of assessment may lead to anomalies and those who have to decide on protection must exercise judgement. For example, a steel-framed building may be found to have a low risk factor but, as the addition of an air termination and earthing system will give greatly improved protection, the cost of providing this may be considered worthwhile.

A low risk factor may result for chimneys made of brick or concrete. However, where chimneys are free standing or where they project for more than 4·5 m above the adjoining structure, they will require protection regardless of the factor. Such chimneys are, therefore, not covered by the method of assessment. Similarly, structures containing explosives or flammable substances are also not covered (*see* **8.2.2**).

Results of calculations for different structures are given in Table 2 and a specific case is worked through in **7.1.8**.

8.1.8 *Sample Calculation of Need for Protection*

A hospital building is 10 m high and covers an area of 70 m × 12 m. The hospital is located in flat country and isolated from other structures. The construction is of brick and concrete with a non-metallic roof

Is lightning protection needed ?

a) *Flashes/km²/year* — Let us say, for the protection of the hospital a value for N_g is 0·7.

b) *Collection area* — Using equation (1) in **8.1.2**:

$$\begin{aligned} A_0 &= (70 \times 12) + 2\ (70 \times 10) + 2\ (12 \times 10) + (\pi \times 100) \\ &= 840 + 1\,400 + 240 + 314 \\ &= 2\,794\ \text{m}^2 \end{aligned}$$

c) *Probability of being struck* — Using equation (2) in **8.1.2**:

$$\begin{aligned} P &= A_0 \times N_g \times 10^{-6} \text{ times per year} \\ &= 2\,794 \times 0{\cdot}7 \times 10^{-6} \\ &= 2{\cdot}0 \times 10^{-3} \text{ approximately} \end{aligned}$$

d) *Applying the weighting factors*

A = 1·7
B = 0·8
C = 1·7
D = 2·0
E = 0·3

The overall multiplying factor = A × B × C × D × E = 1·7

Therefore, the overall risk factor = $2{\cdot}0 \times 1{\cdot}7 \times 10^{-3}$ = $3{\cdot}4 \times 10^{-3}$

Conclusion: Protection is necessary.

8.2 Zone of Protection

8.2.0 *General*

In simple terms, the zone of protection is the volume within which a lightning conductor gives protection against a direct lightning stroke by directing the stroke to itself. For a vertical conductor rising from ground level, the zone has been defined as a cone with its apex at the tip of the conductor its base on the ground. For a horizontal conductor the zone has been defined as the volume generated by a cone with its apex on the horizontal conductor moving from end to end.

NOTE — This standard describes the cone-concept of protection. This is under review.

8.2.1 *Protective Angle*

The so-called 'protective angle' illustrated in Fig. 3 cannot be precisely stated. This is because it depends upon the severity of the stroke and the presence within the protective zone of conducting objects providing independent paths to earth. All that can be stated is that the protection afforded by a lightning conductor increases as the assumed protective angle decreases.

However, for the practical purpose of providing an *acceptable degree* of protection for an ordinary structure, the protective angle of any single component part of an air termination network, namely either one vertical or one horizontal conductor is considered to be 45° (*see* Fig. 3A and 3B). Between three or more vertical conductors, spaced at a distance not exceeding twice their height, the equivalent protective angle may, as an exception, be taken as 60° to the vertical; an example is given in Fig. 3C. For a flat roof, the area between parallel horizontal conductors is deemed to be effectively protected if the air termination network is arranged as recommended in **12.1.2**.

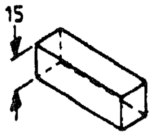
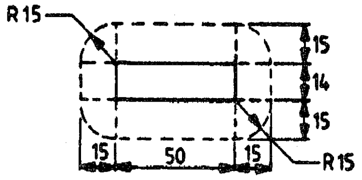
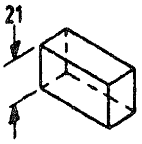
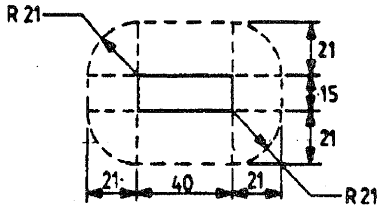
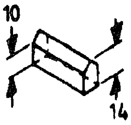
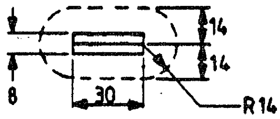
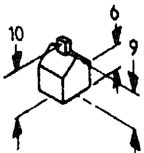
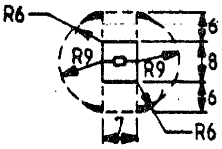
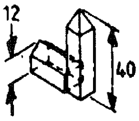
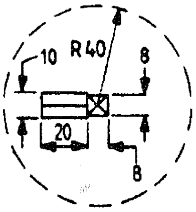
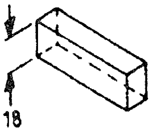
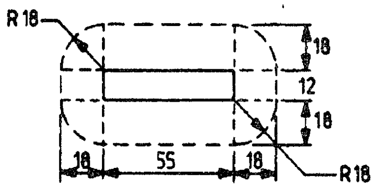
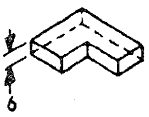
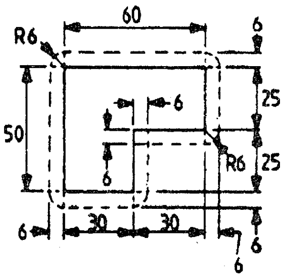
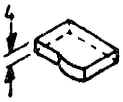
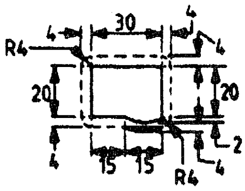
For structures requiring a higher degree of protection, other protective angles are recommended (*see* **16**).

Table 2 Examples of Calculations for Evaluating the Need for Protection

(*Clauses* 8.1.4 *and* 8.1.7)

Sl No. **Description of Structure** (*see* **Fig. 2**)	**Risk of Being Struck (*P*)**			**Weighting Factors**					**Overall Multiplying Factor (Product of cols 5-9)**	**Overall Risk Factor (Product of cols 4 and 10)**	**Recommendation**
	Collection Area A_c	Flash Density N_g	P $A_c \times N_g \times 10^{-6}$	'A' Use of Structure (Table 1A)	'B' Type of Construction (Table 1B)	'C' Contents or Consequential Effects (Table 1C)	'D' Degree of Isolation (Table 1D)	'E' Type of Country (Table 1E)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1) Maisonette, reinforced con-crete and brick built, nonmetallic roof	3 327	0·6	2×10^{-3}	1·2	0·4	0·3	0·4	0·3	0·02	4×10^{-5}	Protection required
2) Office building, reinforced concrete construction, non-metallic roof	4 296	0·6	$2{\cdot}6 \times 10^{-3}$	1·2	0·4	0·3	0·4	0·3	0·02	$5{\cdot}2 \times 10^{-5}$	Protection required
3) School, brick built	1 456	0·7	1×10^{-3}	1·7	1·0	1·7	0·4	0·3	0·3	3×10^{-4}	Protection required
4) 3 bedroom detached dwelling house, brick built	405	0·4	$1{\cdot}6 \times 10^{-4}$	0·3	1·0	0·3	0·4	0·3	0·01	$1{\cdot}6 \times 10^{-6}$	No protection required
5) Village church	5 027	0·6	3×10^{-3}	1·3	1·0	1·7	2·0	0·3	1·3	$3{\cdot}9 \times 10^{-3}$	Protection required

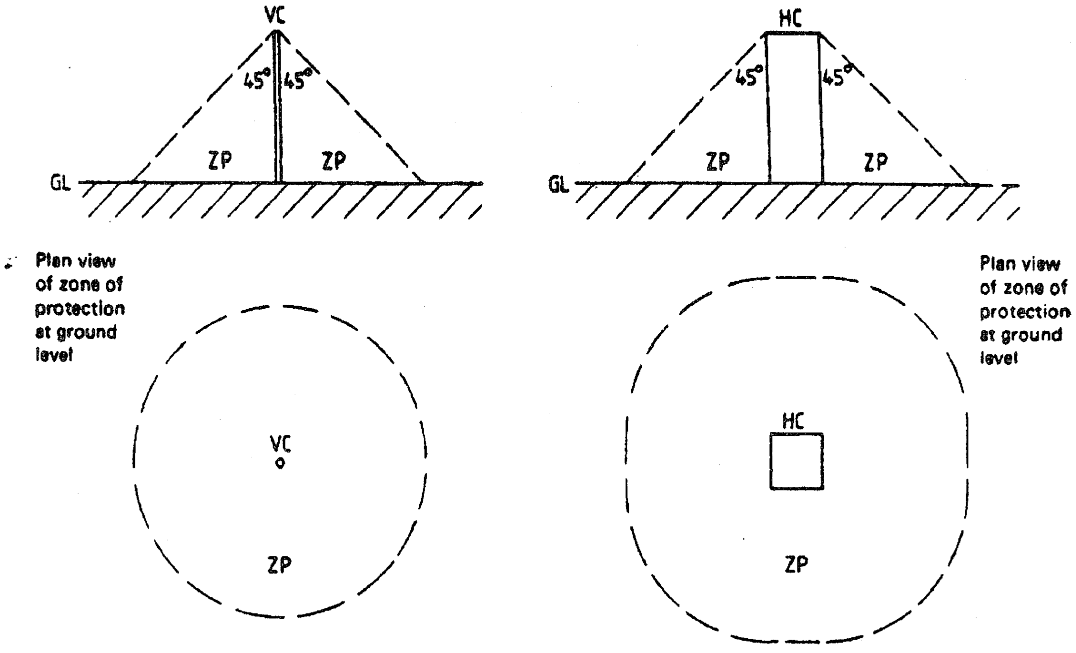
NOTE — The risk of being struck, '*P*' (col 4), is multiplied by the product of the weighting factors (col 5 to 9) to yield an overall risk factor (col 11). This should be compared with the acceptable risk (1×10^{-5}) for guidance on whether or not to protect.

Reference	General arrangement	Collection area and method of calculation
(a)		 $A_c = 14 \times 50 + 2(15 \times 50) + 2(15 \times 14) + \pi 15^2$ $A_c = 3327\ m^2$
(b)		 $A_c = 15 \times 40 + 2(21 \times 40) + 2(21 \times 15) + \pi 21^2$ $A_c = 4296\ m^2$
(c)		 $A_c = \pi 14^2 + 2(14 \times 30)$ $A_c = 1456\ m^2$
(d)		 $A_c = 7 \times 8 + 2(6 \times 7) + \pi 9^2 +$ + 10 (approx.) for areas in black $A_c = 405\ m^2$
(e)		 $A_c = \pi 40^2$ $A_c = 5027\ m^2$
(f)		 $A_c = 12 \times 55 + 2(18 \times 55) + 2(18 \times 12) + \pi 18^2$ $A_c = 4090\ m^2$
(g)		 $A_c = 25 \times 60 + 25 \times 30 + 6 \times 60 + 6 \times 50 + 6 \times 25 + 6 \times 25 + 6 \times 30 + 6 \times 24 + {}^5/_4\, \pi 6^2$ $A_c = 3675\ m^2$
(h)		 $A_c = 20 \times 30 + 2(4 \times 30) + 2(4 \times 20) + \pi 4^2 +$ + 20 (approx.) for area in black $A_c = 1070\ m^2$

All dimensions in metres.

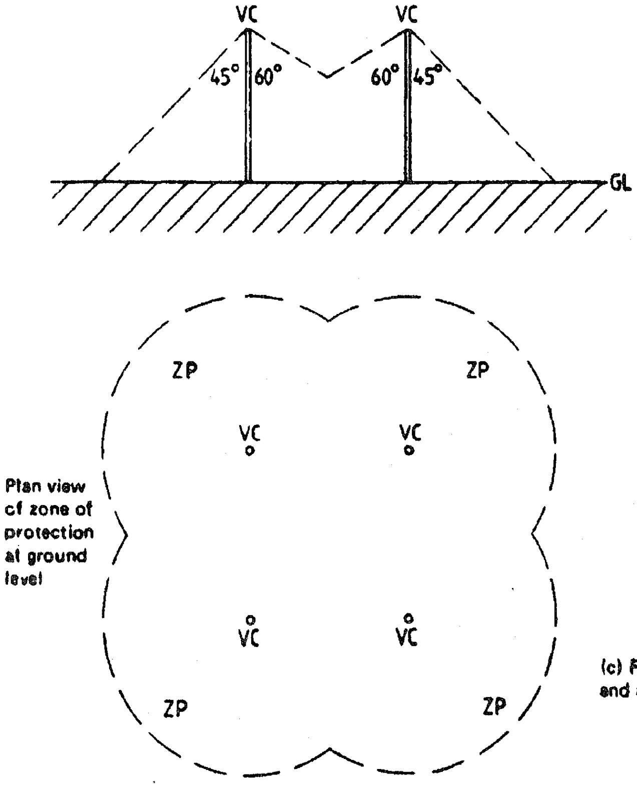
NOTE — This figure should be used in conjunction with Table 2.

FIG. 2 DETAILS OF STRUCTURES AND COLLECTION AREAS


VC
45°
45°
ZP
ZP
GL
HC
45°
45°
ZP
ZP
GL
Plan view of zone of protection at ground level
VC
ZP
Plan view of zone of protection at ground level
HC
ZP

(a) One vertical conductor

(b) Horizontal air termination



(c) Four vertical conductors showing protective angles and associated zones of protection

FIG. 3 PROTECTIVE ANGLES AND ZONES OF PROTECTION FOR VARIOUS FORMS OF AIR TERMINATION

8.2.2 *Structures of Exceptional Vulnerability*

For structures of exceptional vulnerability, by reason of explosive or highly flammable contents, every possible protection may need to be provided, even against the rare occurrence of a lightning discharge striking within the protected zone defined above. For this reason, a reduced zone of protection, and various other special measures should be taken as recommended in **16**.

SECTION 2 SYSTEM DESIGN

9 GENERAL CONSIDERATIONS OF DESIGN

9.0 Exchange of Information

9.0.1 The structure or, if the structure has not been built, the drawings should be examined taking account of the recommendations of this Code and giving particular attention to:

a) metal used in and on the roof, window cleaning rails, handrails (*see* Fig. 4), metal screens, walls, framework or reinforcement above or below ground, to determine the suitability of such metal in place of, or for use as a component of, the lightning protective system. For example, sheet piling should be borne in mind under earth termination networks since this form of making contact with the general mass of the earth is unlikely to be improved upon by rods or tapes; and

b) available positions for the required number of down conductors between the air termination network and the earth termination network, this being particularly important when the down conductors are run internally.

All parts of the structures should, as a general rule, come within the zone of protection.

9.0.2 *Consultation*

Consultation should take place between the designer of the lightning protective system and the following interested parties before and during all stages of design:

a) *Architect* — As far as practicable, the following should be determined:

   1) The routing of all conductors.
   2) The general areas available for earth termination networks and reference electrodes.
   3) The material(s) for conductors.
   4) The extent of the work and the division of responsibility for primary fixings to the structure, especially those affecting the watertightness of the fabric, chiefly roofing.
   5) The material(s) to be used in the structure, especially for any continuous metal, for example stanchions of reinforcement.
   6) The use to which the structure is to be put.
   7) Details of all metallic service pipes, rails and the like entering or leaving the structure or within the structure which may require bonding to the lightning protective system.
   8) The extent of any buried services which could affect the siting of the earth termination network(s).
   9) Details of any equipment, apparatus, plant or the like to be installed within or near the building and which would require bonding to the lightning protective system.

b) *Public Utilities* — Agreement should be reached on the bonding of their services to the lightning protective system. Because of the introduction of new materials and practices, reliance should not be placed on agreements reached for other structures.

c) *Fire/Safety Officers* — Agreement should be reached on:

   1) the need for a lightning protective system on structures containing flammable or explosive materials,
   2) routes and material(s) of construction of duct and sealing at floors if internal conductors are envisaged, and
   3) the method of lightning protection to be adopted in the unlikely event of a structure having a flammable roof.

d) *Television/radio installers* — Agreement should be reached on the need to bond aerial supports and screens of cables to the lightning protective system.

e) *Builder* — Agreement should be reached on:

   1) the form, positions, and numbers of primary fixings to be provided by the builder;
   2) any fixings provided by the lightning protective system contractor to be installed by the builder;

3) the positions of conductors to be placed beneath the structure;
4) whether any components of the lightning protective system are to be used during the construction phase, for example, the permanent earth termination network (ETN) could be used for earthing cranes, railway lines, scaffolding, hoists and the like during construction;
5) for steel-framed structures, the numbers and positions of stanchions and the form of fixing to be made for the connection of earth terminations;
6) whether metallic roof coverings, where used, are suitable as part of the lightning protective system and then to agree the method of attachment of conductors to earth;
7) the nature and location of services entering the structure above and below ground including railway lines, crane rails, wire ropeways, conveyor systems, television and radio aerials and their metal supports, metal flues, flue-liners and dry risers;
8) the position and number of flagmasts, roof level plant rooms (for example lift motor rooms, ventilating, heating and air-conditioning plant rooms), water tanks, and other salient features;
9) the construction to be employed for roofs and walls in order to determine appropriate methods of fixing conductors, specifically with a view to maintaining the weather-tightness of the structure;
10) possible penetration of a waterproofing membrane where earth terminations have to be sited beneath the structure, especially in 'urban' situations and in confined spaces on industrial sites. The same general consideration applies to the 'reference earth electrode' for use in initial and periodic testing;
11) the provision of holes through the structure, parapets, cornices, etc, to allow for the free passage of the lightning or down conductor;
12) the provision of bonding connections to a steel frame, reinforcement bars, and other metal;
13) the most suitable choice of metal for the conductors taking account of corrosion, especially at bimetallic contacts;
14) the accessibility of testing joints, protection by non-metallic casings from mechanical damage or pilferage, lowering of flagmasts or other removable objects, facilities for periodic inspection, especially on chimneys; and
15) the preparation of a drawing incorporating the above details and showing the positions of all conductors and of the main components.

10 MATERIALS

10.1 Table 3 gives a check list for materials to be used in the component parts of lightning protective systems.

Copper and aluminium are recommended for installations required to have a long life. If there is any difficulty in the use of copper or aluminium, galvanized steel of the same cross section as recommended for copper may be used. Galvanized steel may be preferred for some short life installations, such as exhibitions.

In making a choice, consideration should always be given to the risk of corrosion, including galvanic corrosion.

10.2 When non-matallic materials are used, their possible degradation due to ultra-violet light, frost, etc, must be borne in mind and the advantages of easy installation and no electrogalvanic corrosion should be considered along with need to replace them more frequently.

For the protection of conductors due consideration must be given to protective coatings to preclude corrosion in less-favourable environments.

For example:

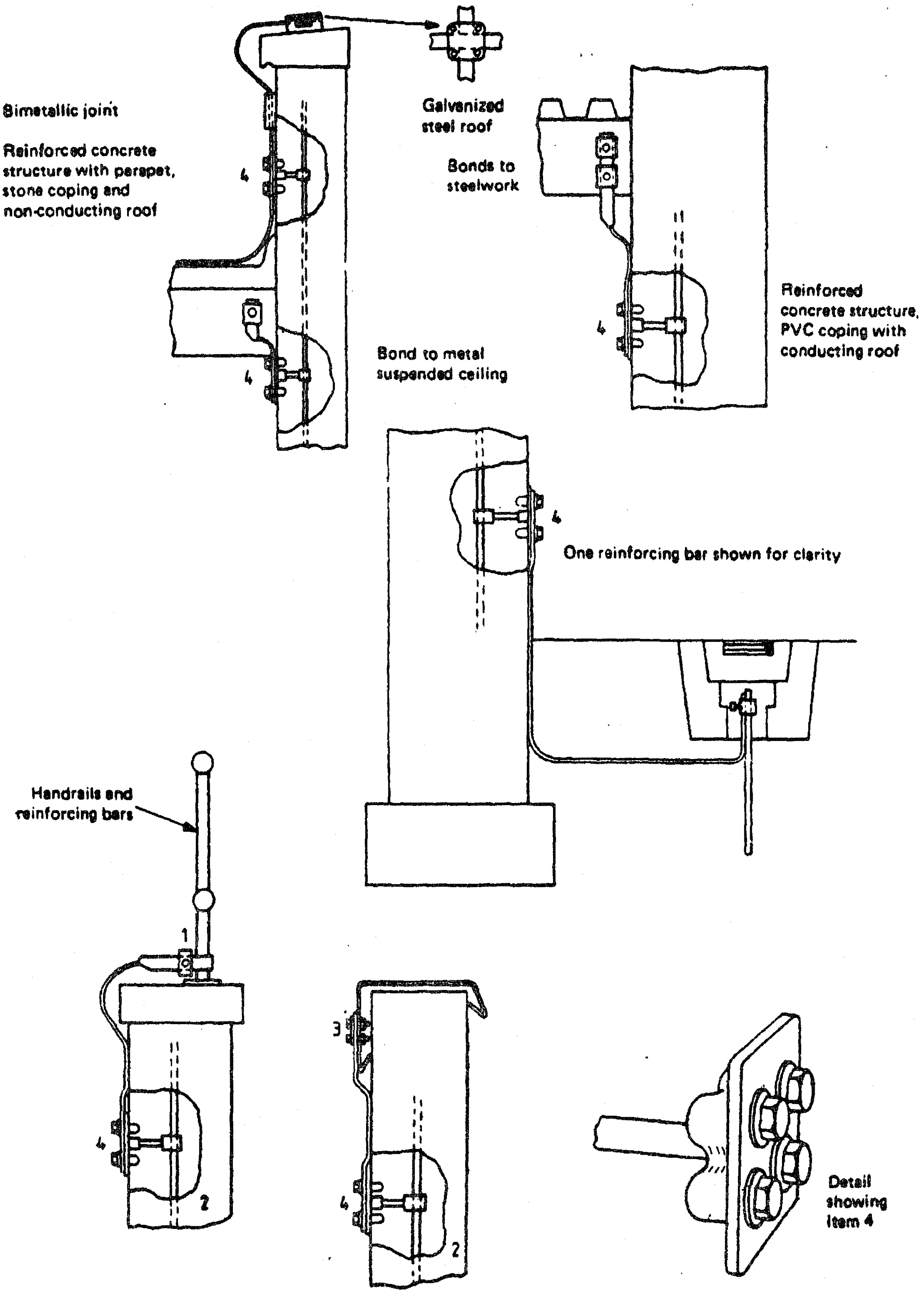
a) Lead covered (2 mm minimum thickness of coating) strip is most suitable for protection at the top of chimneys. Lead sheathing should be sealed at both ends and the sheathing should not be removed when making joints;

b) PVC covering (1 mm thickness of coating) will protect copper, steel and aluminium in many environments. Where insulating coatings or coverings are used, due regard should be given to their durability and flammability.

10.3 Although in the past it has been common practice to use material in the form of strip for horizontal air terminations, down conductors and bonds, it may sometimes be more convenient to use rod material, particularly as it facilitates the making of bends in any plane.

Internal bonds are permitted to have approximately half the cross-sectional area of external bonds. Flexible bonds may be used.

Stainless steel in contact with aluminium or aluminium alloys is likely to cause additional corrosion to the latter materials. In these cases it is important to take protective measures such as using inhibitors.


Bimetallic joint
Reinforced concrete structure with parapet, stone coping and non-conducting roof
4
4
Galvanized steel roof
Bonds to steelwork
Bond to metal suspended ceiling
Reinforced concrete structure, PVC coping with conducting roof
4
4
One reinforcing bar shown for clarity
Handrails and reinforcing bars
1
4
2
3
4
2
Detail showing item 4

Key : 1. Handrails bond
2. Reinforcing bond
3. Coping bond
4. Non-ferrous bonding point (built-in)

FIG. 4 EXAMPLES OF AIR TERMINATIONS AND DOWN CONDUCTORS USING HANDRAILS, METAL COPINGS AND REINFORCING BARS

Table 3 List of Recommended Materials for Component Parts

(*Clause* 10.1)

Material
Castings
Leaded gunmetal
Aluminium alloy
Bars and Rods
Copper, hard drawn or annealed
Copper-cadmium
Phosphor bronze
Naval brass
Copper silicon
Aluminium
Galvanized steel
Sheet
Copper
Aluminium and aluminium alloys
Strip
Copper, annealed
Aluminium
Galvanized steel
Stranded Conductors for Catenary Systems
Hard drawn copper and copper cadmium
Aluminium
Aluminium alloy
Aluminium steel-reinforced
Galvanized steel
Fixing Bolts and Screws for Copper
Phosphor bronze
Naval brass
Copper silicon
Fixing Bolts and Screws for Aluminium and Aluminium Alloys
Aluminium alloy
Stainless steel
Galvanized steel
Rivets for aluminium and aluminium alloy
Rivets for copper
Stranded or Solid Conductors Insulated
Copper
Aluminium
Flexible Conductors
Copper

NOTE — Guidelines on the specific grade or type of each material suitable and their characteristic are under consideration.

11 DIMENSIONS

11.1 The component parts of lightning protective systems should have dimensions not less than those given in Tables 4 and 5 except in special case considered in **20.4**. In situations where inspection or repair is likely to be unusually difficult, consideration should be given to using a size bigger than the minimum given in Table 4.

The nearest standard size should be used, provided that the dimension is not appreciably smaller than that stated.

12 COMPONENT PARTS

12.0 The principal components of a lightning protective system are:

a) air terminations,
b) down conductors,
c) joints and bonds,
d) testing joints,
e) earth terminations, and
f) earth electrodes.

These are dealt with in detail in **12.1**, **12.2**, **12.3** and **12.4**. Where necessary, the component parts are diagramatically shown in Fig. 5 to 27, and typical designs of various fixings are shown in Fig. 28 to 30.

12.1 Air Terminations

12.1.1 *Basic Rules*

Air termination networks may consist of vertical or horizontal conductors or combinations of both (for example *see* Fig. 5 to 8).

No part of the roof should be more than 9 m from the nearest horizontal protective conductor (*see* Notes under Fig. 6).

All metallic projections, including reinforcement, on or above the main surface of the roof which are connected, intentionally or fortuitously, to the general mass of the earth, should be bonded to, and form part of, the air termination network (*see* Fig. 4, 11 and 12).

Metallic coping, roof coverings, handrails (*see* **13**) and window washing equipment and metallic screens around play areas should be considered for inclusion as part of the air termination network (*see* Fig. 4, 10 and 12).

If portions of a structure vary considerably in height, any necessary air terminations or air termination networks for the lower portions should be bonded to the down conductors of the taller portions in addition to their own down conductors.

Table 4 Minimum Dimensions Component Parts

(*Clause* 11.1)

Component	Dimensions mm	Area mm^2
Air terminations		
Aluminium, copper and galvanized steel strip	20 × 3	60·00
Aluminium, aluminium alloy or, phosphor bronze and galvanized steel rods	10·0 dia	78·54
Suspended conductors		
Stranded aluminium	19/2·14	70·00
Stranded copper	19/2·14	70·00
Stranded aluminium/steel reinforced		
Stranded galvanized steel	6/4·72	100·00
Down conductors		
Aluminium, copper or galvanized steel strip	20 × 3	60·00
Aluminium, aluminium alloy galvanized steel rods	10·0 dia	78·54
Earth terminations		
Hard-drawn copper rods for direct driving into soft ground	12·0 dia	113·00
Hard-drawn or annealed copper rods for indirect driving or laying under ground	10·0 dia	78·54
Phosphor bronze for hard ground	12·0 dia	113·00
Copper-clad or galvanized steel rods (*see* Notes 1 and 2 for hard ground)	10·0 dia	78·54
Fixed connection(s) in aluminium, aluminium alloy, copper, galvanized steel		
External		
Strip	20 × 3	60·00
Rods	10·0 dia	78·54
Internal		
Strip	20 × 1·5	30·00
Rods	6·5 dia	33·00
Stranded flexible connection (bonds)		
External, aluminium	560/0·5	70·00
External, annealed copper	990/0·3	70·00
Internal, aluminium	276/0·4	35·00
Internal, annealed copper	1 107/0·2	35·00

NOTES

1 For copper clad steel rods the core should be of low carbon steel with a tensile strength of approximately 700 N/mm^2. The cladding should be of 99·9 percent electrolytic copper molecularly bonded to the steel core. The radial width of the copper should not be less than 0·25 mm.

2 Stranded conductors are not normally used for down conductors or earths.

Table 5 Minimum Thicknesses of Sheet Metal Used for Roofing

(*Clause* 11.1)

Material	Minimum Thicknesses mm
Steel, galvanized	0·5
Stainless steel	0·4
Copper	0·3
Aluminium and zinc	0·7
Lead	2·0

NOTE — These figures are based on contemporary building practice and will be satisfactory where the roofs form part of the lightning protecting system. However, damage by way of puncturing may occur with a direct arc-connected stroke (*see also* 27.2.4).

12.1.2 *Forms of Air Termination*

In practice, very few of the many forms of structure can be protected by any reasonable arrangement of single conductors. Recommendations for various forms of air termination (*see* Fig. 4). Guidance on their application are given in **12.1.2.1** to **12.1.2.5**. Although, for the sake of clarity, down conductors and earth terminations have been omitted from the figures, it should be understood that these should be provided as recommended in this Code, taking account, as necessary, of the architectural and structural features of the structure and of the site conditions.

12.1.2.1 *Simple vertical conductor(s)*

Figure 3A shows a simple vertical conductor and the zone of protection in plan and elevation.

Figure 3B shows five vertical conductors with the increased angle of protection available between them. The zones of protection for this arrangement are illustrated in the general sketch. However, it must be realised that although in suitable cases advantage may be taken of the increased protective zone, there can be no reality about the precise shape of the envelope, since this is only a statistical concept.

12.1.2.2 *Horizontal conductor(s) for flat roofs*

Figure 3C shows a simple horizontal air termination consisting of a roof conductor around the periphery of a rectangular building. The resulting zone protection is shown in plan and elevation.

Figure 5 shows a typical arrangement for a structure with a large area of flat roof where **12.1.1** strongly recommends the employment of a system of horizontal roof conductors. The maximum spacing of 18 m is shown, this applies to structures without special inherent risk.

12.1.2.3 *Structures with complex geometry*

Figures 6, 8 and 13 show the type of building formed by a large rectangular block with several abutting smaller blocks. The main block is protected by a horizontal air termination consisting of a peripheral roof conductor, subsidiary roof conductors being used for the abutting buildings where these are outside the zone of protection of the main structure. The additional structures shown on the roof of the main block are typical of tank rooms or plant rooms for lifts. These are outside the protective zone of the main roof conductor and are shown individually protected by a peripheral conductor, in one case, and by a vertical conductor on the flagmast in the other. In the latter case, the whole of the additional roof structure falls within the protective cone of the vertical conductor.

All elements of the lightning protective system are to be bonded together as recommended in **12.2.9** and **12.2.10**.

Figure 7 shows two examples of common profiles for roofs covering large areas. Horizontal air terminations are shown consisting of ridge conductors bounded at either end by conductors following the roof profiles.

12.1.2.4 *Tiled roofs*

On non-conducting roofs the conductor is placed under the ridge tiles because of the difficulty of fixing it to the upper side of a tiled surface without impairing its waterproof properties. As it is the explosion pressure wave associated with a direct lightning strike which lifts roof coverings, from this point of view it is immaterial whether the conductor is mounted above or below the roof surface (*see* Fig. 14).

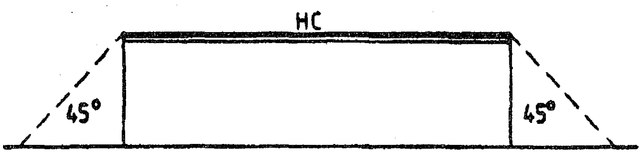
12.1.2.5 *Simple structures with explosive hazards*

Figure 15 shows the type of installation primarily intended for simple structures with explosive hazards. It consists of two vertical conductors connected by a horizontal catenary wire. The zone of protection is shown in plan and elevation and reflects the effect of the sag in the catenary wire.

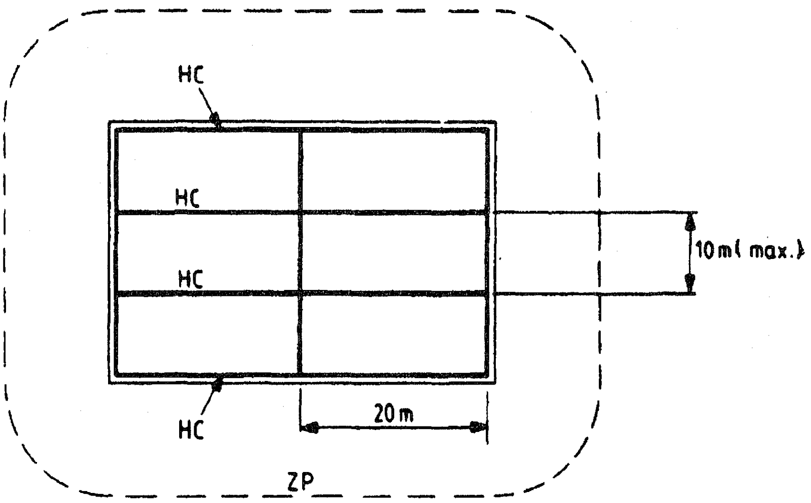
12.2 Down Conductors

12.2.1 *General*

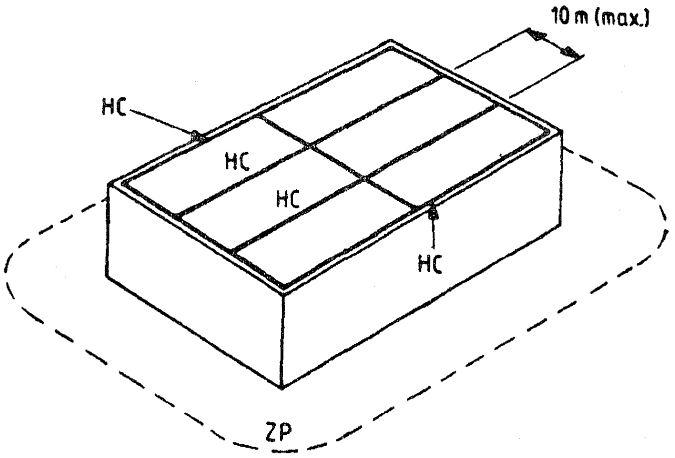
The function of a down conductor is to provide a low impedance path from the air termination to the earth electrode so that the lightning current can be safely conducted to earth.



(a) Elevation showing protective angle

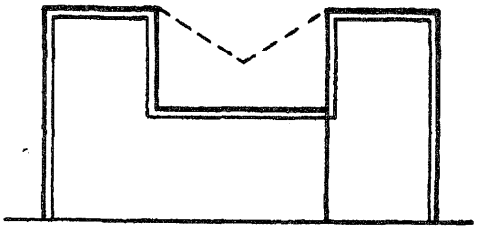


(b) Plan showing zone of protection at ground level

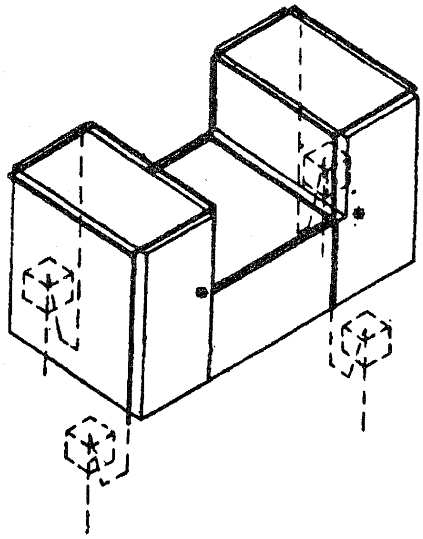


(c) General arrangement

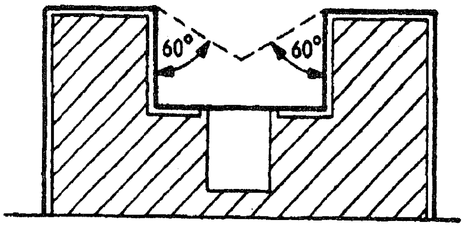
FIG. 5 AIR TERMINATIONS FOR A FLAT ROOF



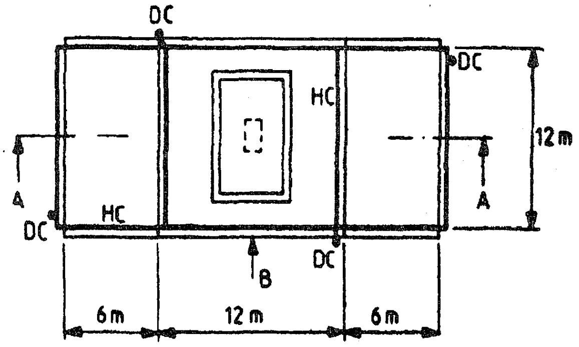
View from B



*Join down conductors and horizontal conductors on lower parapet.



Section A-A



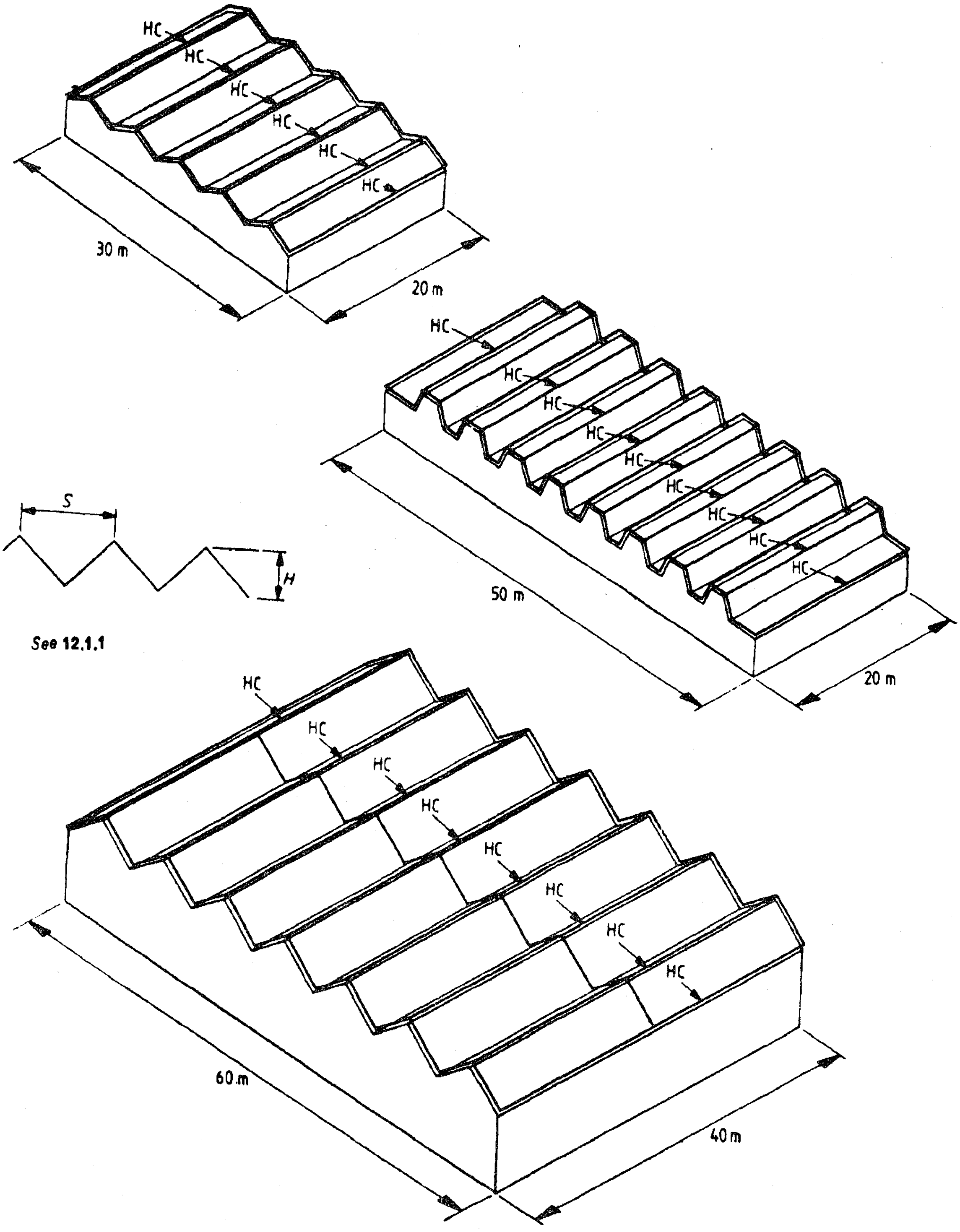
Perimeter = 24 + 24 + 12 + 12 = 72 m
Number of down conductors required (*see* **12.2.3**) = 72/20 = 4.

NOTES

1 An air termination along the outer perimeter of the roof is required and no part should be more than 5 m from the nearest horizontal conductor, except that an additional 1 m may be allowed for each metre by which the part to be protected is below the nearest conductor.

2 Horizontal conductors are not necessary on the parapets of the light well; a zone of protection of 60° is provided by the two adjacent horizontal conductors for structures less than 20 m high. This principle does not apply to taller structures.

FIG. 6 AIR TERMINATIONS FOR FLAT ROOFS AT DIFFERENT LEVELS



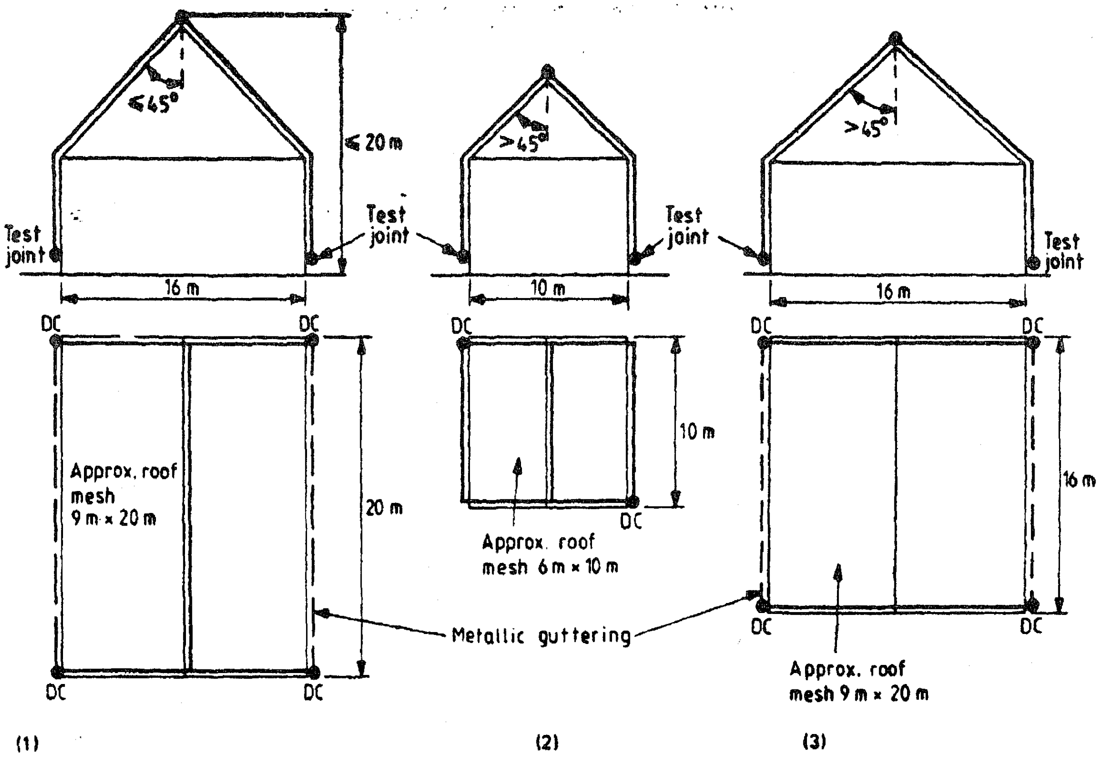
NOTES

1 If $S > 10 + 2H$, additional longitudinal conductors are required so that the distance between conductors does not exceed 10 m.

2 If the length of the roof exceeds 20 m, additional transverse conductors are required.

3 Down conductors are omitted for clarity.

FIG. 7 AIR TERMINATIONS FOR LARGE AREAS OF ROOF OF VARIOUS PROFILES



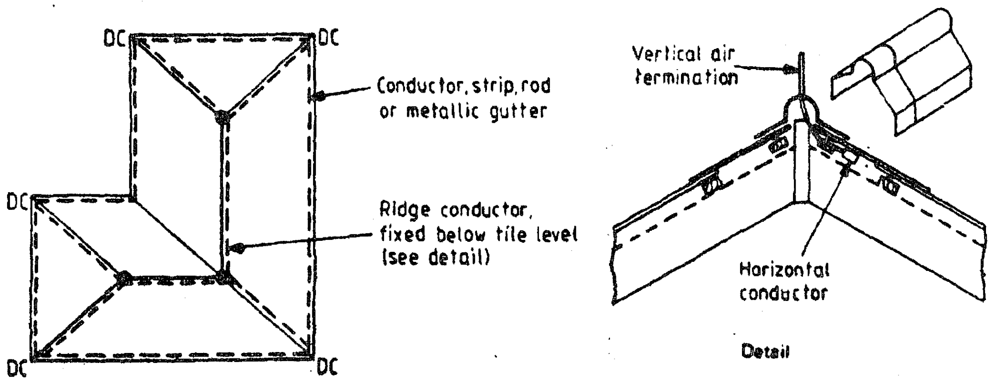
NOTE. The protective angle provided by the ridge conductor in each case is as follows:

figure (1) protective angle up to 45°: ridge conductor is sufficient with connection to metallic gutters; number of down conductors = 72/20 = 3.6 (say 4);

figure (2) protective angle over 45°: air termination mesh (maximum 10 m X 20 m); ridge and eaves conductors provide approximate roof mesh 6 m X 10 m; number of down conductors = 40/20 = 2;

figure (3) situation as for figure (2) but metallic gutters used in lieu of eaves conductor: number of down conductors = 64/20 = 3.2 (say 4).

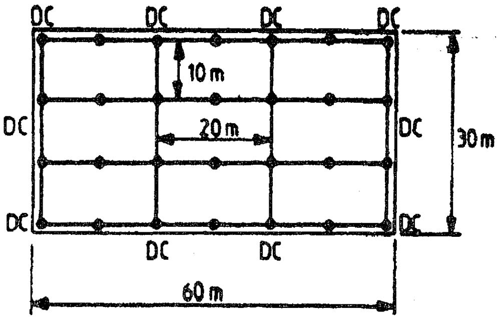
(a) Air terminations and down conductors


DC
DC
Conductor, strip, rod or metallic gutter
DC
Ridge conductor, fixed below tile level (see detail)
DC
DC
Vertical air termination
Horizontal conductor
Detail

Key—Concealed conductors - - - - 0·3 m high bare vertical rods ●.

(b) Air terminations below roof covering

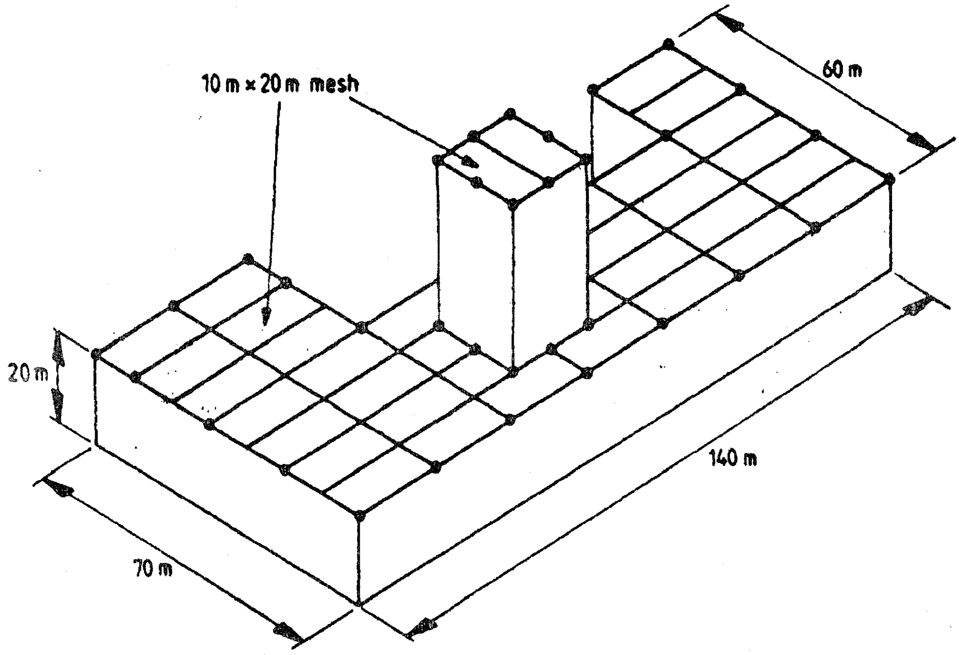
FIG. 8 AIR TERMINATIONS AND CONCEALED CONDUCTORS FOR BUILDINGS LESS THAN 20 m HIGH WITH SLOPING ROOFS



Key — 0·3 m high bare vertical rods ●.

NOTE — Where PVC covered horizontal air termination conductors are used, bare vertical rods 0·3 m high should be fixed at each intersection and at intermediate positions along the horizontal conductors spaced no more than 10 m apart [*see* **10.2**(b)].

FIG. 9A AIR TERMINATIONS AND DOWN CONDUCTORS FOR FLAT ROOF BUILDINGS WHERE THE AIR TERMINATION CONDUCTORS HAVE A PVC OVERSHEATH

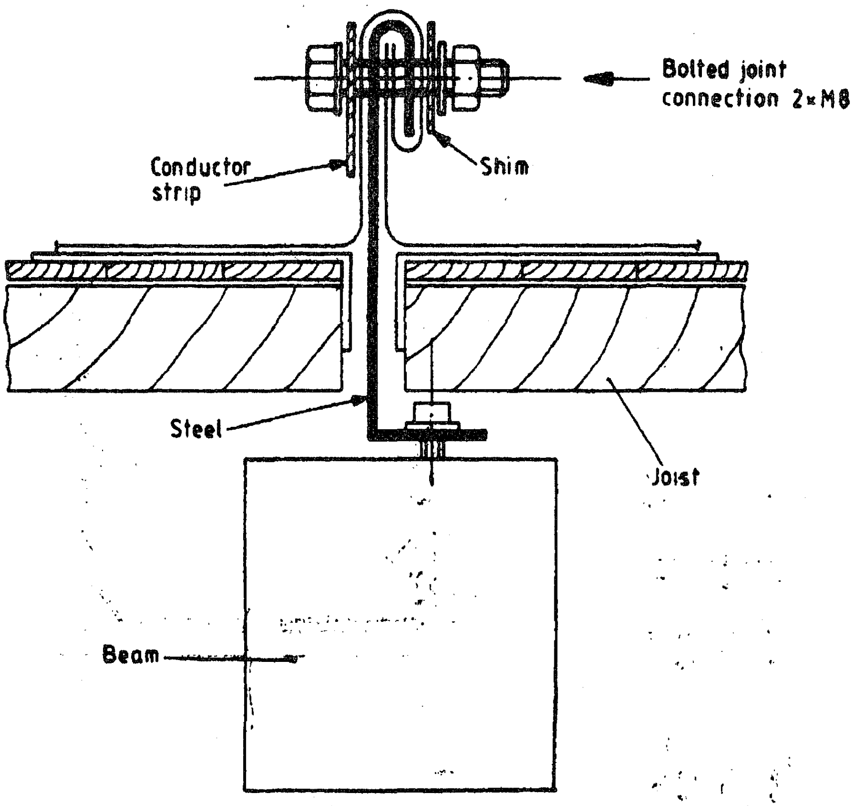


NOTE — The air termination network for a tall reinforced concrete or steel framed structure should be as follows:

a) Horizontal conductors on roofs form a 10 m × 20 m network;

b) There are bonds to steelwork at corners, 20 m intervals around periphery and at the base of the tower, 0·5 m above roof level.

FIG. 9B AIR TERMINATIONS FOR TALL CONDUCTING STRUCTURES



NOTE — Minimum dimensions when a metallic roof covering is used as part of the air termination network are as follows:

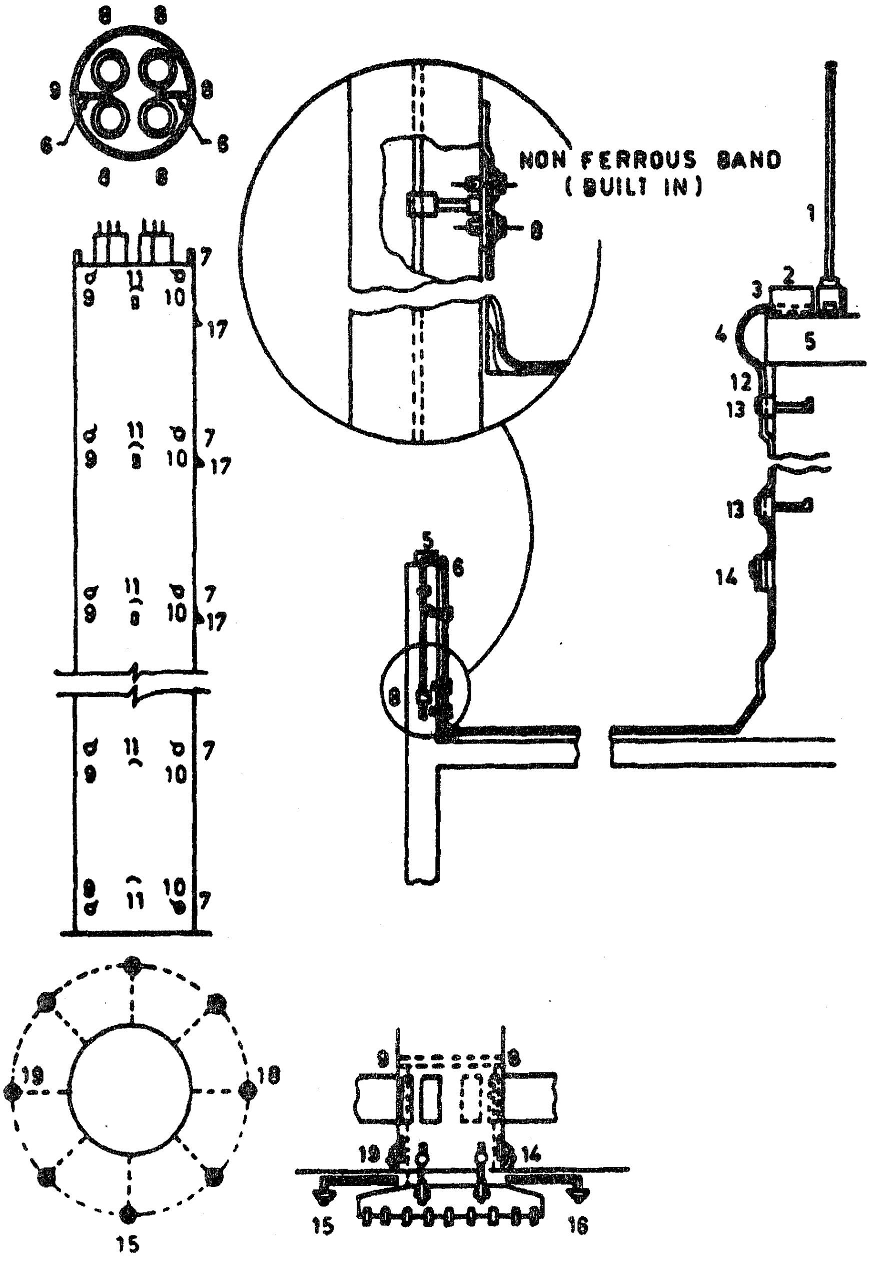
Galvanized steel	0·5 mm
Copper	0·3 mm
Aluminium	0·7 mm
Zinc	0·7 mm
Lead	2·0 mm

Fig. 10 Air Termination for a Flat Roof Showing Connection to Standing Seam Joint When a Metallic Roof is Used as Part of the Air Termination Network

In practice, depending upon the form of the building, it is often necessary to have many down conductors in parallel, some or all of which may be part of the building structure itself. For example, a steel framed building might need no added down conductors, the framework itself providing an efficient natural network of many paths to earth; conversely a structure made entirely from non-conducting materials would need down conductors deployed according to its size and form.

In brief, the down conductor system must, where practicable, be directly routed from the air termination to the earth termination network, and be symmetrically placed around the outside walls of the structure starting from the corners. In all cases consideration to side flashing must always be given (*see* **12.2.5**).

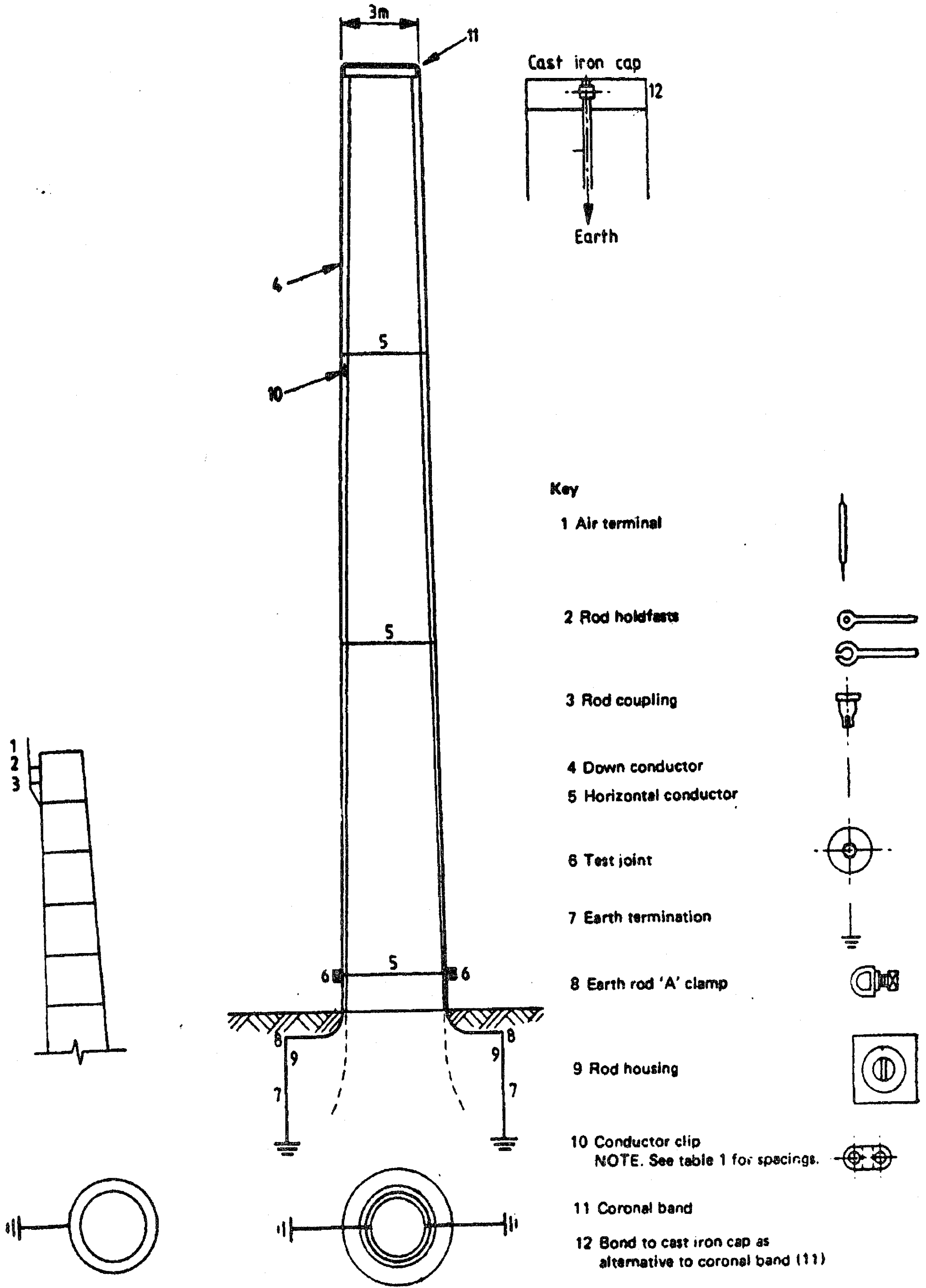
NOTE — It should be noted that a steel framed structure built on a reinforced concrete raft approaches the case of a Faraday cage. A reinforced concrete structure is similar to a steel framed structure in that they both provide a multiple system of down conductor.



*1 Air terminal
*2 Air terminal base
*3 Pot metal filling
4 Lead covered tape
5 Coronal
6 Coronal firings
7 Hand rail bond
8 Bond to R. I.
9 Bond to platform
10 Bond to ladder
11 Bond to lift shaft
12 Down conductor
13 Down conductor fixings
14 Test clamp
15 Earth rod
16 Earth rod clamp
17 Aircraft warning lights
18 Connection to common earth
19 Earth strip

*Alternative bond to a cast iron cap.

FIG. 11 LIGHTNING PROTECTION SYSTEM — TALL CHIMNEY WITH CONCRETE WINDSHIELD AND BRICK FLUES

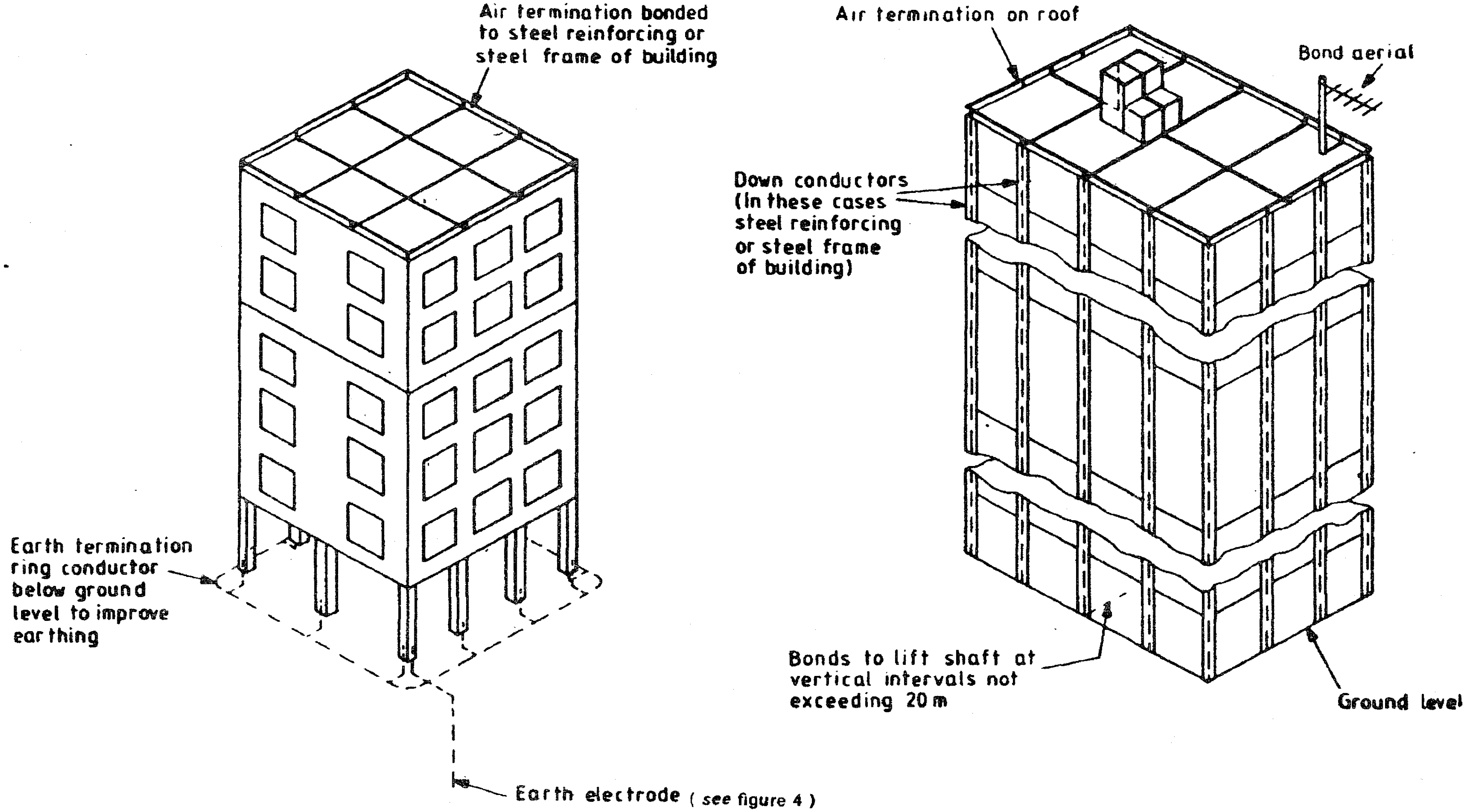


a) Chimneys less than 1·5 m diameter at top and 20 m high

b) 60 m brick stack

All dimensions in metres.

FIG. 12 LIGHTNING PROTECTION SYSTEM FOR A BRICK CHIMNEY-STACK


Air termination bonded to steel reinforcing or steel frame of building
Earth termination ring conductor below ground level to improve earthing
Earth electrode (see figure 4)
Air termination on roof
Bond aerial
Down conductors (In these cases steel reinforcing or steel frame of building)
Bonds to lift shaft at vertical intervals not exceeding 20 m
Ground level

NOTE — Air termination mesh should be not greater than 10 m × 20 m. Down conductors should be not more than 10 m apart.

Fig. 13 Lightning Protection System for Tall Buildings (Over 20 m High) Showing Air Terminations, Down Conductors. Bonds to Projections Above Roof (Including Bonds to Lift Motor Room and Lift Shaft)

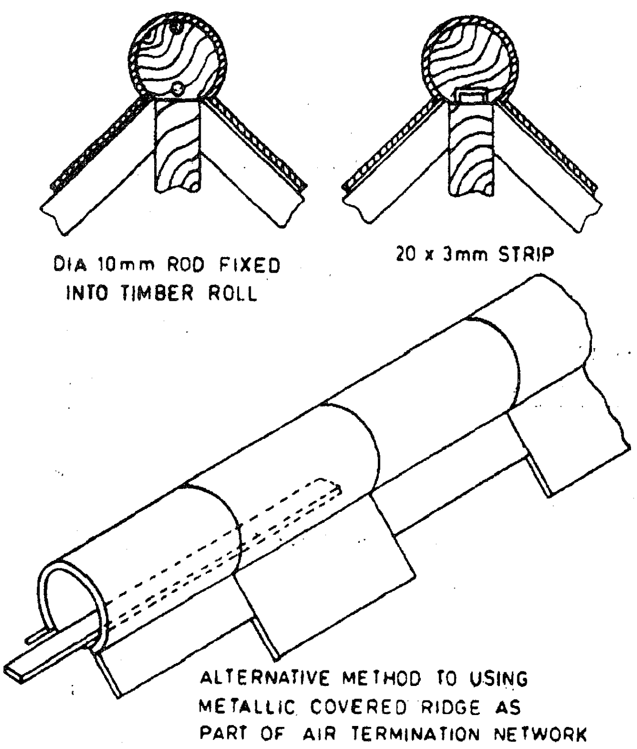

DIA 10mm ROD FIXED INTO TIMBER ROLL
20 x 3mm STRIP
ALTERNATIVE METHOD TO USING METALLIC COVERED RIDGE AS PART OF AIR TERMINATION NETWORK

FIG. 14 AIR TERMINATIONS FOR TILED ROOFS

Design requirements are given below.

12.2.2 *Pattern of Down Conductors*

Various types of structures, with and without steel frames are illustrated in Fig. 16. Explanatory notes are given below:

Figure 16(a) represents a steel framed building. No added down conductors are, therefore, required but earthing is essential in accordance with this code.

Figure 16(b) shows a down conductor pattern where on the North, East and South sides, the upper floors are cantilevered.

Figure 16(c) illustrates a pattern where a ballroom and/or swimming pool and terrace might be situated on the South and West sides.

Figures 16(d), 16(e), 16(f) and 16(g) are of such shape as to permit all down conductors to be on the outside walls; care should be taken to avoid entrance and exit areas by appropriate choice of down conductor spacing taking account of the need to avoid dangerous voltage gradients along the ground surface (*see also* 21.5 and Fig. 17).

12.2.3 *Recommended Number*

The position and spacing of down conductors on large structures is often governed by architectural convenience, however, recommendations for their number are given below:

a) A structure having a base area not exceeding 100 m^2 need have only one down conductor, except when built on bare rock where specialist advice should be sought, or where access for testing is difficult.

b) For a structure having a base area exceeding 100 m^2, the number of down conductors should be at least the smaller of the following:

   1) one plus an additional one for each 300 m^2, or a part thereof, in excess of the first 100 m^2; and

   2) one for each 30 m of perimeter of the structure protected.

12.2.4 *Tall Structures Presenting Inspection Difficulties*

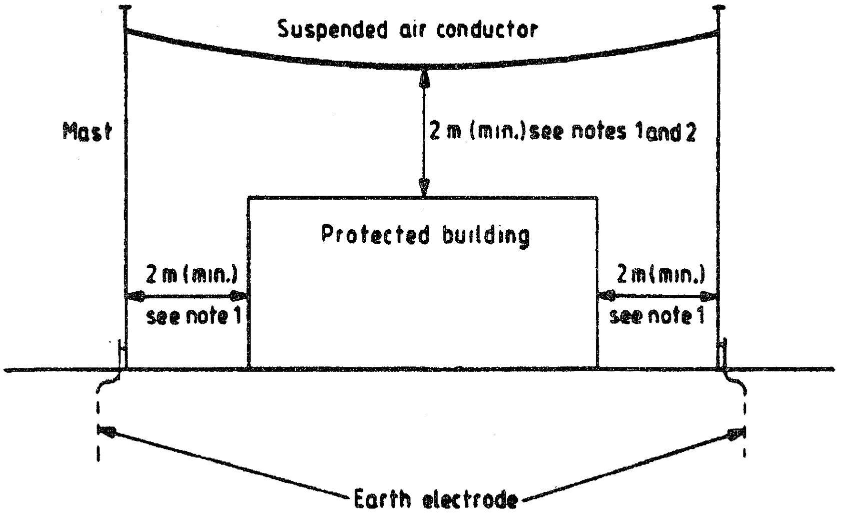
For tall structures, where testing and inspection could be difficult, consideration should be given to providing a means for the testing of continuity in the system. At least two down conductors will be required for such tests (*see* Fig. 12).

12.2.5 *Routing*

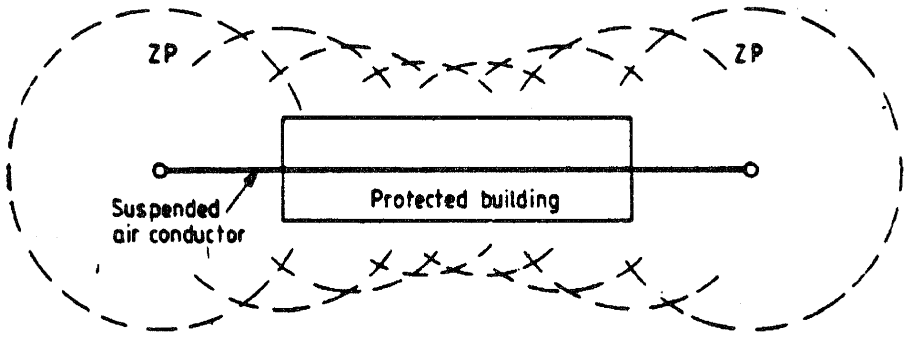
A down conductor should follow the most direct path possible between the air terminal network and the earth termination network. Where more than one down conductor is used, the conductors should be arranged as evenly as practicable around the outside walls of the structure (*see* Fig. 16).

In deciding the route, taking account of the above, the possibility should be considered of incorporating structural steelwork, such as, stanchions, reinforcement, and any continuous and permanent metal parts of the structure suitably disposed for purposes of acting as a down conductor.

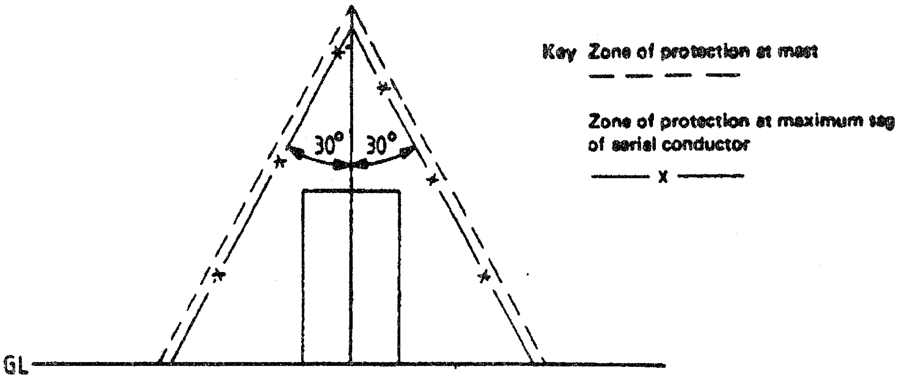
The walls of light wells may be used for fixing down conductors but it is strongly advised that lift shafts should not be used for this purpose.



(a) Elevation



(b) Plan


30°
30°
GL
Key Zone of protection at mast
— — — —
Zone of protection at maximum sag of aerial conductor
—— x ——

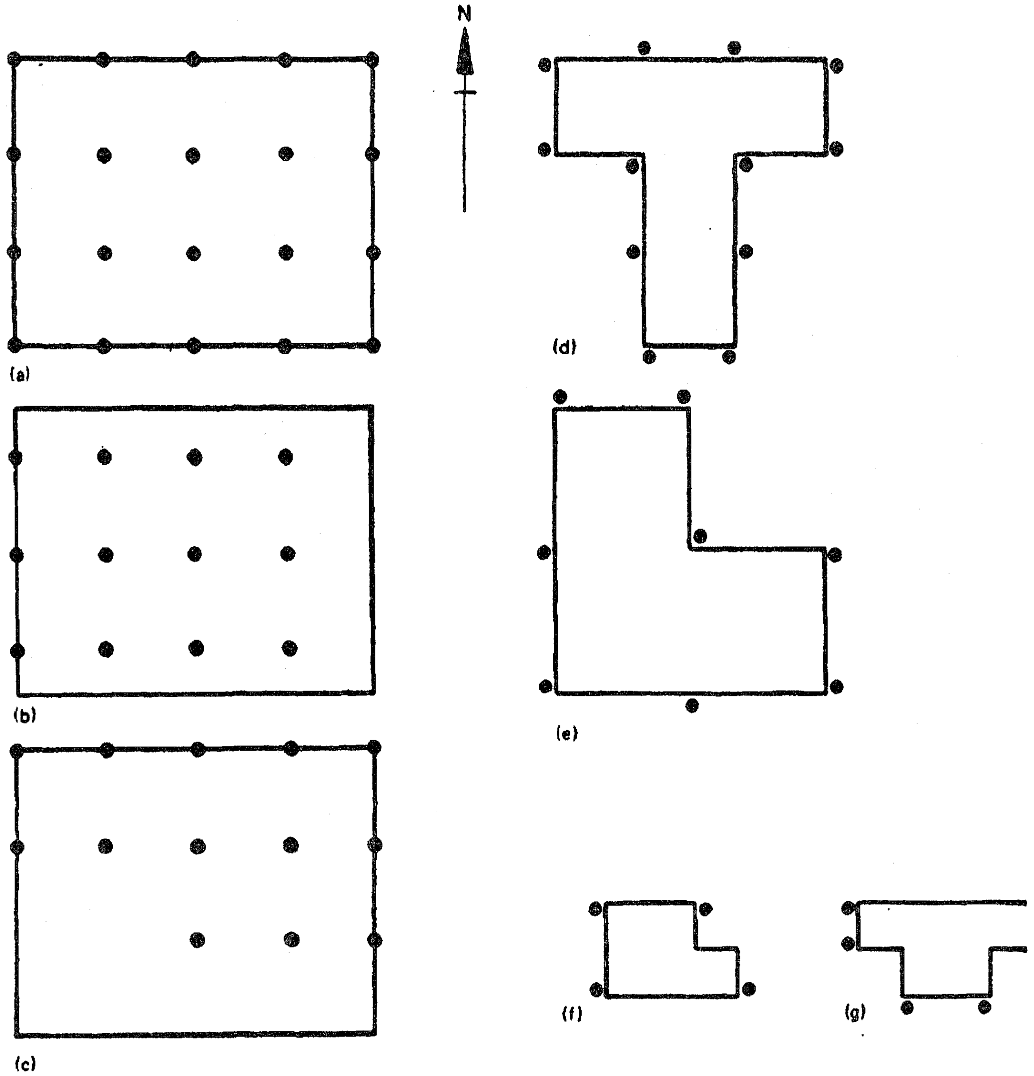
(c) Zone of protection

NOTES

1 To prevent flashover between mast/conductor and protected building, the minimum clearance distance has to be 2 m or as governed by 12.5.2, whichever is the greater.

2 This clearance has to be as above under maximum sag conditions, i.e. snow and ice on the aerial conductor.

FIG. 15 AIR TERMINATION AND ZONE OF PROTECTION FOR SIMPLE STRUCTURE WITH EXPLOSIVE OR HIGHLY FLAMMABLE CONTENTS



NOTES

1 The down conductors may be natural (parts of the building framework) or added strip or rod on external faces (*see* **11.2.2**).

2 On structures exceeding 20 m in height, down conductors should be spaced at not more than 10 m apart (*see* **13**).

Fig. 16 Patterns of Down Conductors (Natural or not) for Various Forms of Tall Building

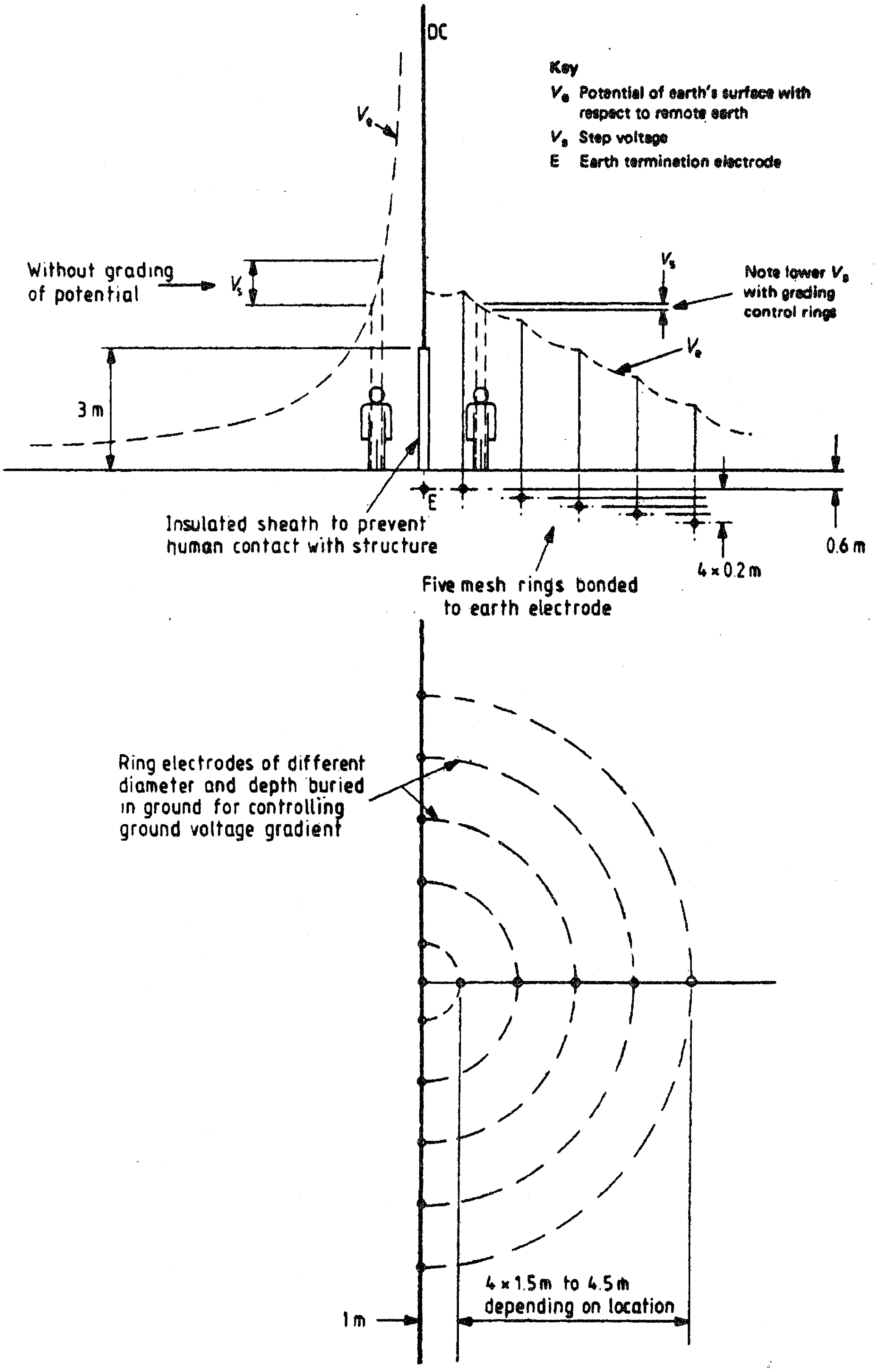

DC
Key
V_e Potential of earth's surface with respect to remote earth
V_s Step voltage
E Earth termination electrode
V_e
Without grading of potential
V_s
3 m
V_s
Note lower V_s with grading control rings
V_e
E
Insulated sheath to prevent human contact with structure
Five mesh rings bonded to earth electrode
4 × 0.2 m
0.6 m
Ring electrodes of different diameter and depth buried in ground for controlling ground voltage gradient
4 × 1.5 m to 4.5 m depending on location
1 m

FIG. 17 VOLTAGE GRADIENTS ALONG GROUND SURFACE NEAR TO MASTS, TOWERS, COLUMNS AND SINGLE DOWN CONDUCTORS ON BUILDINGS

12.2.6 *Use of Reinforcement in Concrete Structures*

Details should be decided at the design stage, before building construction begins [*see* **9.0.2**(e) (12)].

12.2.6.1 *Electrical continuity*

The metal bars of a reinforced concrete structure cast *in-situ* are occasionally welded, thus providing definite electrical continuity. More frequently, however, they are tied together by metal binding wire at crossing points but, despite the fortuitous nature of the metallic connection, the very large number of bars and crossing points of such a construction assures a substantial sub-division of the total lightning current into a multiplicity of parallel discharge paths. Experience shows that such a construction can be readily utilised as part of the lightning protective system.

The following precautions are, however, recommended:

a) Good contact between reinforcing bars to be ensured by fixing the bars with tying wire, and

b) Ties should be provided for both vertical to vertical bars and horizontal to vertical bars.

12.2.6.2 *Electrolytic corrosion* — Under consideration.

12.2.6.3 *Prestressed concrete members*

It is not permitted to connect lightning protection conductors to prestressed concrete columns, beams or braces.

12.2.6.4 *Precast concrete members*

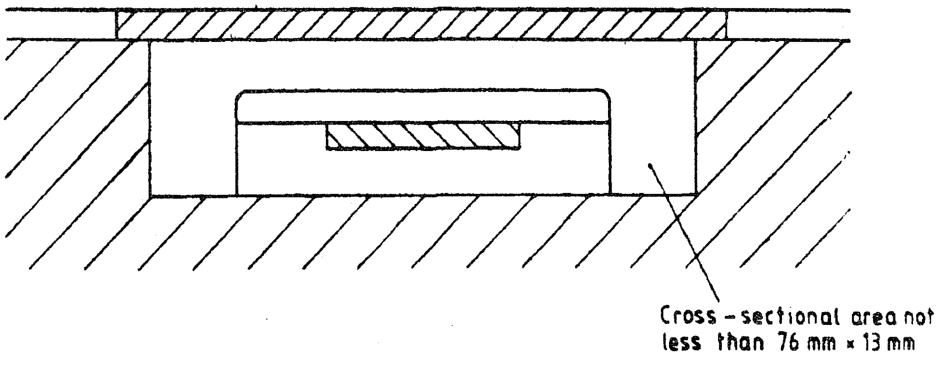
In the case of precast reinforced concrete columns, beams or braces, the reinforcement may be used as a conductor if the individual elements of reinforcement are bonded together and electrical continuity is ensured.

12.2.7 *External Routes not Available*

Where the provision of suitable external routes for down conductors is impracticable or inadvisable, for example in buildings of cantilever construction from the first floor upwards, down conductors should not follow the outside contours of the building. To do so would create a hazard to persons standing under the overhang. In such cases, down conductors may be housed in an air space provided by a non-metallic non-combustible internal duct and taken straight down to ground (*see* Fig. 18).

Any suitable covered recess not smaller than 76 mm × 13 mm or any suitable vertical service duct running the full height of the building may be used for this purpose provided it does not contain an unarmoured or non-metal-sheathed service cable.

In cases where an unrestricted duct is used, seals at each floor level may be required for fire protection. As far as possible, access to the interior of the duct should be available.



NOTE — The non-combustible duct should have a two-hour fire rating.

FIG. 18 DOWN CONDUCTOR IN INTERNAL DUCT

12.2.8 *Sharp Bends and Re-entrant Loops*

Practical reasons do not always allow the most direct route to be followed. Whilst sharp bends, such as arise at the edge of a roof are permissible, re-entrant loops in a conductor can produce high inductive voltage drops so that the lightning discharge may jump across the open side of the loop. As a rough guide, this risk may arise when the length of the conductor forming the loop exceeds 8 times the width of the open side of the loop (*see* Fig. 19).

When large re-entrant loops as defined cannot be avoided, such as in the case of some cornices or parapets, the conductor should be arranged in such a way that the distance across the open side of a loop complies with the rule quoted. Alternatively, such cornices or parapets should be provided with holes through which the conductor can pass freely.

12.2.9 *Bonding to Prevent Side-Flashing*

Any metal in or forming part of the structure on any building services having metallic parts which by design or fortuitously are in contact with the general mass of the earth should be either isolated from or bonded to the down conductor (*see* **12.5**).

The same general recommendation applies to all exposed large metal items whether connected to earth or not. (In this context a large item is considered as one having any single dimension greater than 2 m.) Minor items such as door hinges, metal gutter brackets, reinforcement of small isolated beams may be disregarded.

12.2.10 *Bonds*

12.2.10.1 *General*

Most parts of a lightning protective system are specifically designed to fit into an overall plan. Bonds, however, have to join a variety of metallic parts of different shapes and composition and cannot, therefore, be of standard form. Because of their varied use, there is the constant problem of corrosion and careful attention must be given to the metals involved, that is metal from which the bond is made and those of the items being bonded.

12.2.10.2 *Mechanical and electrical requirements*

A bond must be mechanically and electrically effective and protected from corrosion in and erosion by the operating environment.

External metal on, or forming part of, a structure may have to discharge the full lightning current and its bond to the lightning protective system should have a cross sectional area not less than that employed for the main conductors. On the other hand, internal metal is not nearly so vulnerable and its associated bonds are, at most, only likely to carry a proportion of the total lightning current, apart from their function of equalizing potentials. These latter bonds may, therefore, be smaller in cross-sectional area than those used for main conductors.

12.2.10.3 *Provision for bonding of future equipment*

In all buildings, at each floor level, provision should be made for bonding future machinery or equipment to the lightning protective system, such as by connection to metallic gas, water, drainage or similar services. Structures supporting overhead electric supply, telephone and other lines must not be bonded to a lightning protective system without the permission of the appropriate authority.

12.2.10.4 *Joints*

Any joint other than welded represents a discontinuity in the current conducting system and is susceptible to variation and failure. Accordingly, the lightning protective system should have as few joints as possible.

Joints should be mechanically and electrically effective, for example clamped, screwed, bolted, crimped, riveted or welded. With overlapping joints, the length of the overlap should not be less than 20 mm for all types of conductors. Contact surfaces should first be cleaned, then inhibited from oxidation with a suitable non-corrosive compound. Joints of dissimilar metals should be protected against corrosion or erosion from the elements or the environment and should present an adequate contact area (*see also* Fig. 20, 21 and 22).

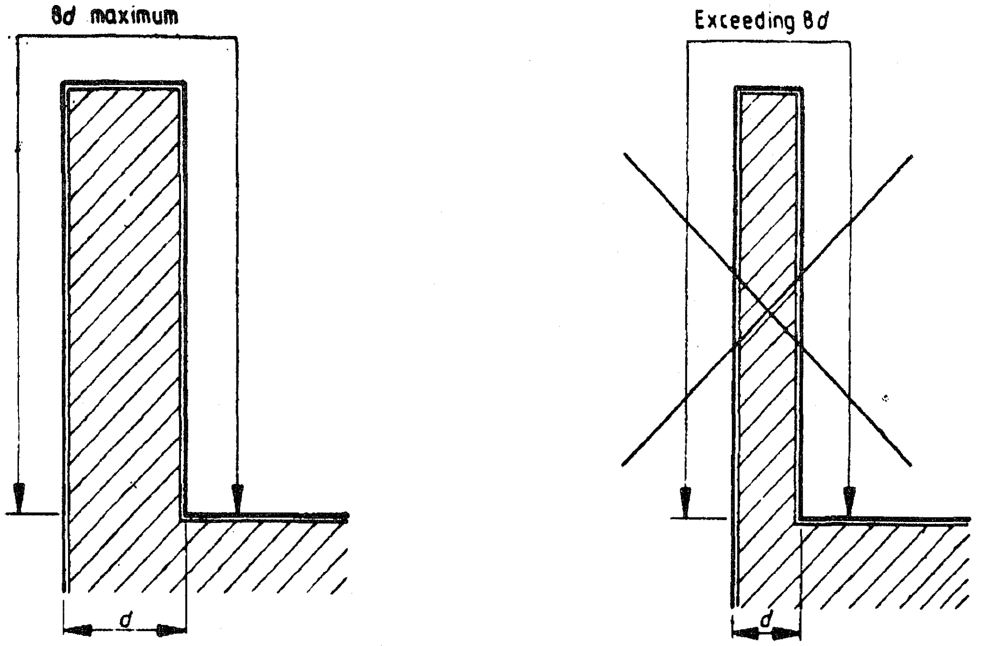
12.2.11 *Test Points*

Each down conductor should be provided with a test clamp in such a position that, whilst not inviting unauthorized interference, it is convenient for use when testing.

12.3 Earth Termination Network

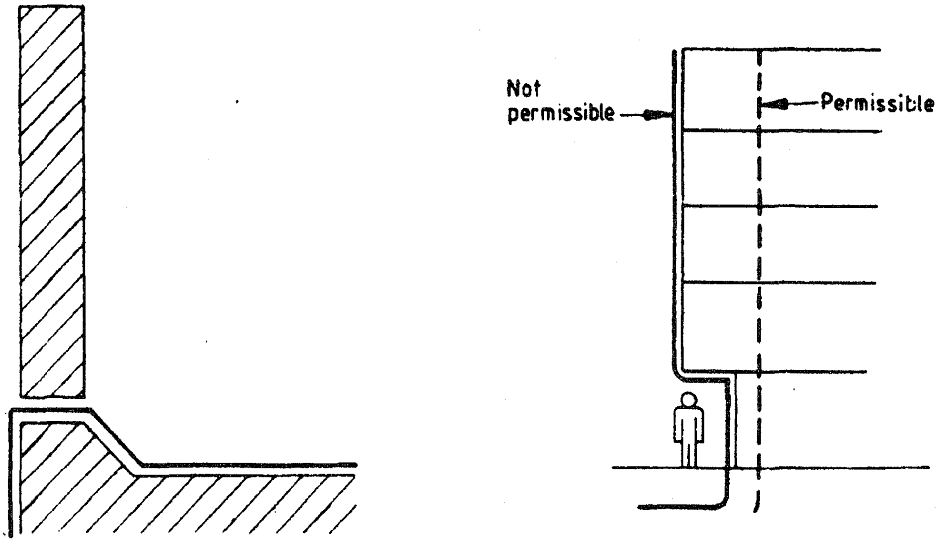
12.3.1 *Resistance To Earth*

An earth electrode should be connected to each down conductor. Each of these earths should have a resistance not exceeding the product given by 10 Ω multiplied by the numbre of earth electrodes to be provided. The whole of the lightning protective system, including any ring earth, should have a combined resistance to earth not exceeding 10 Ω without taking account of any bonding.



(a) Permissible arrangement

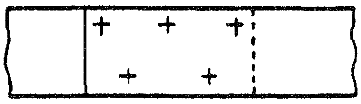
(b) Arrangement that is not permissible



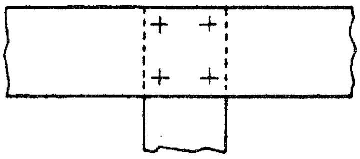
(c) Permissible method of taking conductor through a parapet wall

(d) Routes for down conductors in a building with cantilevered upper floors

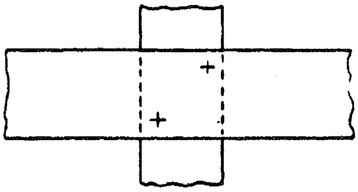
Fig. 19 Re-Entrant Loops



STRAIGHT JOINT



TEE JOINT



CROSS JOINT

NOTE — All riveted joints should be prepared and made in accordance with **12.2.10.4** (*see* Fig. 21 and 22 for protection of joints.)

FIG. 20 TYPICAL JOINTS

The resistance to earth after the completion of bonding should be noted and used in all subsequent testing (*see* **12.3.4** and **24**).

If the value obtained for the whole of the lightning protective systems exceeds 10 Ω, a reduction can be achieved by extending or adding to the electrodes or by interconnecting the individual earth terminations of the down conductors by a conductor installed below ground, sometimes referred to as a ring conductor (*see* Fig. 13).

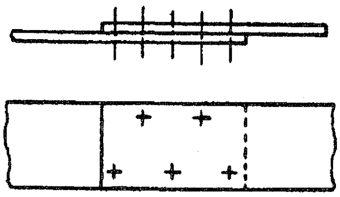
Buried ring conductors laid in the manner described above are considered to be an integral part of the earth termination network and should be taken into account when assessing the overall value of resistance to earth of the installation.

12.3.2 *Importance of Reducing Resistance to Earth*

A reduction of the resistance to earth to a value below 10 Ω has the advantage of further reducing the potential gradient around the earth electrodes when discharging lightning current. It also further reduces the risk of side-flashing to metal in or on a structure (*see* **12.2.9**).

12.3.3 *Common Network for All Services*

A common earth termination network is recommended for the lightning protective system and all other services. It should be in accordance with the recommendations of this code and should also comply with any regulations applicable to the services concerned. The resistance to earth should, in this case, be the lowest value required for any of the individual services (*see* IS 3043 : 1987).



NOTES

1 The strips should be drilled at centres shown in the sketch.

2 The 'mating' surfaces should be effectively wire brushed (using a separate brush for each metal) and treated with an inhibitor.

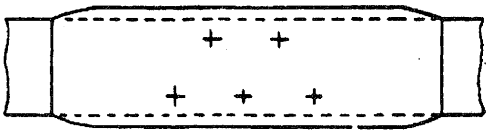
3 The strips should then be joined using rivets.

4 Protection of the joint can be provided by either:

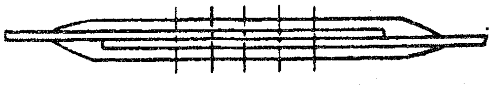
a) solvent cutback, thixotropic corrosion preventative, forming a film or resilient matt petroleum wax; or

b) Fast drying durable rubberized coating sprayed as an aerosol.

FIG. 21 JOINT PROTECTION — METHOD A



DRILLING PATTERN



Procedure

a) The aluminium and copper tapes should be drilled as shown in sketch above.

b) The mating surface of the aluminium tape should be pretinned for a length of 200 mm.

NOTE — A suitable method has been found to use Fry's Alca 'Z' solder and Kynal Flux or Grey and Martin's Amalgam A.L4 Solder and Kynal Flux, all surplus flux must be removed with warm water.

c) The mating surface of the copper tape should be pretinned with a lead/tin solder and all surface flux removed.

d) The tapes should be joined using 5 off rivets, and the joint reheated and solder fed from the top until any spaces are filled; and normal lead/tin solder is suitable for filling.

e) The joint should be wrapped for a length of 250 mm with 25 mm wide EPR tape.

FIG. 22 JOINT PROTECTION — METHOD B

12.3.4 *Isolation of Earth Electrodes for Testing*

Earth electrodes should be capable of being isolated and a reference earth point should be provided for testing purposes.

12.3.5 *Structures on Rock*

A structure standing on rock should be provided with a ring conductor following the contour of the ground. If there is earth cover, it should be used. The ring should be installed under the foundation of a new structure. If there are objections to these recommendations, then at least two strip electrodes should be used or an earth termination can usually be obtained by rock drilling and backfilling the hole with a conducting material before driving the rods. The diameter of the hole should be not less than 75 mm. Coke breeze or fly ash should not be used as backfilling material because of their corrosive nature. The value of 10 Ω for the resistance to earth is not applicable in this case.

12.3.6 *Railway Tracks*

The earthing of rails should be carried out at:

a) the point of entry to, or from the structure;

b) 75 m beyond the point of entry or exit in either direction, that is internally if it is an underground structure or externally if above ground;

c) 150 m beyond the point of entry to, or exit from, the structure in the case of above ground lines; and

d) every 75 m in underground installations.

The same criteria would apply to surface lines on which a travelling crane or hoist was being used.

12.3.7 Further explanatory notes are given in **27**.

12.4 Earth Electrodes

12.4.1 *General*

Before proceeding with a design, a decision on the form of earth electrode most suited to the physical nature of the soil as revealed by trial bore holes is necessary.

Earth electrodes should consist of metal rods, tubes or strips, or a combination of these.

12.4.2 *Ground Conditions*

Where earth rods are used, they should, except in rock (*see* **12.5.5**), be driven into virgin ground, not made-up or backfilled or where the ground is likely to dry out, seasonally, or due to heat from boilers or plant. Coke breeze or fly ash should not be used as backfilling material because of their corrosive nature.

12.4.2.1 *Earth electrode seal for use within a tank structure*

When earth terminations in built-up areas pass through a tank structure, a seal similar to that shown in Fig. 23 should be used.

12.4.3 *Earth Rods*

12.4.3.1 *Location*

When earth rods are used, they should be driven into the ground beneath, or as close as practicable to, the structure and down conductor. The practice of siting terminations 2·5 m to 3 m away from the building is unnecessary and uneconomical (*see* Fig. 24). Where ground conditions are favourable for the use of rods in parallel, the reduction in earth resistance is small when the separation between the rods becomes less than their driven length.

12.4.3.2 *Electrical measurements during installation*

During the driving of the rods it is advisable to take measurements of the resistance to earth. By so doing, an indication will be given of conditions under which it is highly unlikely that any further reduction in resistance will be obtained even if a greater length of rod is driven into the ground.

12.4.3.3 *Connections and indicating plates*

The connection between the down conductor and the rod should be accessible above ground or, if below ground, within an inspection box.

Plates indicating the position and number of electrodes should be fitted above each test point.

12.4.4 *Strips*

12.4.4.1 *Position and form*

When strips are used, they may be buried beneath structure or laid in trenches at depths unlikely to be affected by seasonal drying out or agricultural operations (*see* Fig. 24).

Strips should be disposed radially from the point of connection with a down conductor, the numbers and lengths of strip required being as found necessary to give the desired resistance to earth.

If space restrictions demand the use of a parallel or grid formation of strips, the layout should be as in Fig. 24 where the distance between parallel strips should not be less than 3 m.

12.4.4.2 *Corrosion*

Because of the harmful corrosion which is likely to result, coke breeze should not be allowed to come in contact with copper electrodes and salting of the ground in the vicinity of any earth electrode should not be practised.

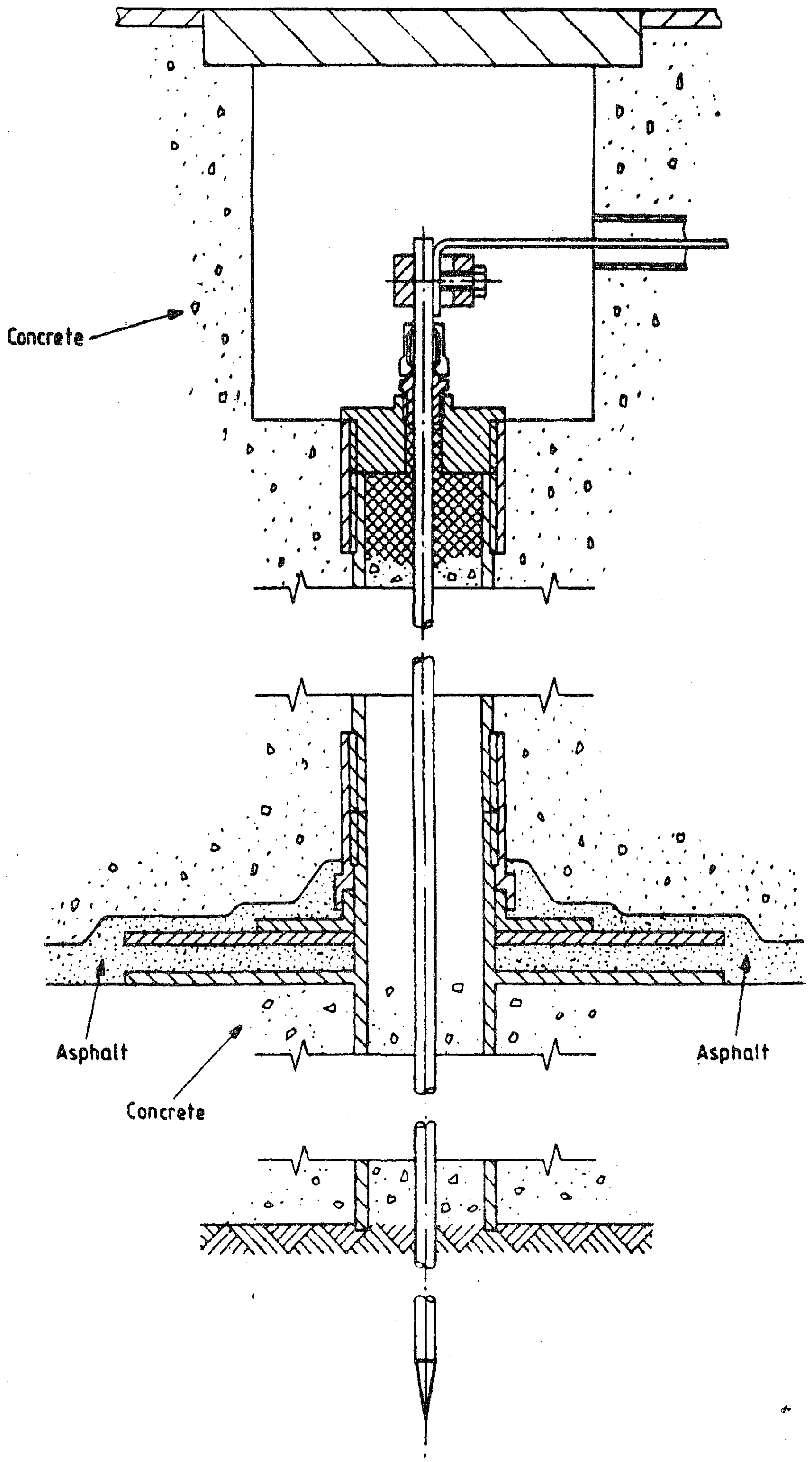
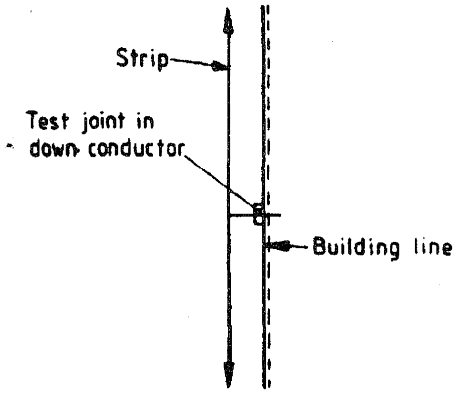
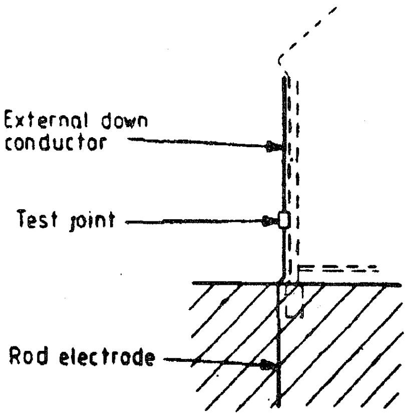


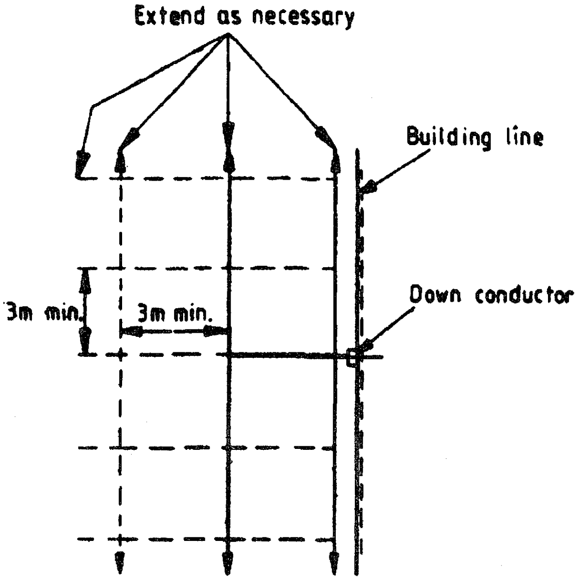
Fig. 23 Example of an Earth Electrode Seal for Use Within a Tanked Structure



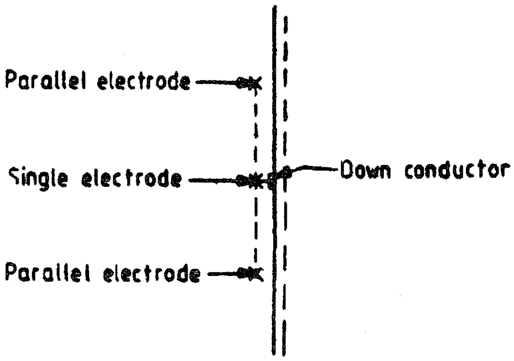
Plan arrangement for single strip bisected by down conductor



Section and elevation of structure



Plan arrangement of strips in parallel (continuous heavy line) or grid formation (broken line)



Plan arrangement

a) Strip electrodes

b) Single or multiple rod electrodes

NOTES

1 When it is necessary for part of an earth termination network to pass near or under a road or pathway, it should be buried not less than 0·6 m below ground level.

2 The electrical potential at ground level can be reduced by burying the rod or strip deeper.

FIG. 24 EARTH TERMINATIONS: ARRANGEMENT OF EARTH ELECTRODES

12.5 Metal in or on a Structure

12.5.1 *General*

When a lightning protective system is struck, its electrical potential with respect to earth is raised and, unless suitable precautions are taken, the discharge may seek alternative paths to earth by side-flashing to other metal in the structure.

There are two different ways of preventing side-flashing, namely:

a) isolation, and
b) bonding.

Isolation requires large clearances between the lightning protective system and other metal in the structure. Its main drawbacks lie in the difficulty of obtaining and maintaining the necessary safe clearances and in ensuring that isolated metal has no connection with the ground, such as through water or other services.

In general, isolation can only be practised in small dwelling houses and bonding is, therefore, the more commonly used method.

12.5.2 *Isolation*

12.5.2.1 *Estimation of clearances to prevent side-flashing*

a) *General* — The necessary clearance to prevent side-flashing depends upon the voltage sustained by the lightning protective system with respect to earth, which in turn depends upon the strength of the current in the lightning flash. The procedure is given in (b), (c) and (d) below.

b) *Determination of current* — To determine the current in the lightning flash, the following steps should be taken:

   1) *Estimate P* — The risk of the structure being struck (*see* **8.1.2**).

   2) Divide the estimated risk, P, by the acceptable risk, P_0 (*see* **8.1.3**).

   3) Decide from Fig. 25 the maximum current likely to occur.

c) *Voltage sustained by lightning protective system* — This has two components: the product of the current and the resistance to earth and the product of the rate of change of current and the inductance of the down conductor. In the worst case, the simple addition of these two products gives the voltage which should then be used in calculations.

d) *Flashover distance/voltage* — Refer to Fig. 26 and read off the flashover voltage against the spacing.

12.5.2.2 *Example of calculation*

An example is given below of the calculation necessary to decide whether to bond metalwork to a lightning protective system:

Given — A cast steel down-pipe is positioned 2 m from the down conductor of the lightning protective system fitted to a block of flats 15 m high situated in a region of high lightning activity, having 1·2 flashes/km²/year. The block of flats is 40 m × 20 m on plan.

Assumptions — Assume that the acceptable risk, P_0, is 1×10^{-5}, that the resistance of the earth termination will be 10 Ω and that the number of down conductors is four.

Question — Should the down-pipe, which has a maximum height of 12 m, be bonded to the lightning protective system ?

Procedure — The plan of the collection area follows: $L = 40$ m, $W = 20$ m and $H = 15$ m.

Collection area A

$$= (L \times W) + 2\ (L \times H) + 2(W \times H) + \pi\, H^2. \quad \ldots(1)$$

$$= (40 \times 20) + 2(40 \times 15) + 2(20 \times 15) + \pi \times 15^2$$

$$= 800 + 1\,200 + 600 + 707$$
$$3\,307 \text{ m}^2 \text{ (say } 3\,300 \text{ m}^2\text{)} \quad \ldots(2)$$

Probability of being struck, P

$$= 1{\cdot}2 \times 3\,300 \times 10^{-6}/\text{year} \quad \ldots(3)$$

$$= 3{\cdot}96 \times 10^{-3} \text{ (say } 4 \times 10^{-3} \text{ or once in } 250 \text{ years)} \quad \ldots(4)$$

Acceptable risk, P_0 — This has been given as 1×10^{-5}.

Which current to use (*see* Fig. 25).

$$P/P_0 = (4 \times 10^{-3})/1 \times 10^{-5} = 4 \times 10^2 = 400\text{A} \ldots(5)$$

Because P is greater than 100 P_0, assume that the maximum lightning current of 200 kA will be achieved. (For small values of P_0, the current will be 100 $\log_{10} P/P_0$ as shown plotted in Fig. 25.)

Voltage between lightning protective system and earthed down-pipe at a height of 12 m

$$V = V_{Re} + V_L \quad \ldots(6)$$

where

V_{Re} is the voltage drop due to the resistance to earth, and

V_L is the voltage drop due to the inductance of the down conductor.

There are four down conductors and, assuming that the current is divided equally among them, then the effective current is 200/4 = 50 kA in each conductor.

$$V_{Re} = 50 \times 10 = 500 \text{ kV} \qquad \text{...(7)}$$

V_L = rate of change of current (kA/μs) (*see* Note 1) × height (m) of downpipe × inductance of down conductor in μH/m (*see* Note 2).

NOTES

1 For a typical wavefront, the maximum rate of change of strike current is roughly 0·6 × I_{peak}, so that for a current of 50 kA the rate of change of current = 30 kA/μs = 3×10^{10} A/s.

2 The inductance of a typical down conductor is taken as 1·5 μH/m.

$$V_L = (\text{ rate of change of current }) \times (\text{ length of conductor }) \times (\mu\text{H/m}) \text{ kV}$$

$$= 30 \times 12 \times 1{\cdot}5$$

$$= 540 \text{ kV} \qquad \text{...(8)}$$

Therefore $V_{Re} + V_L = 500 + 540 = 1\,040$ kV ...(9)

Flashover distance — Look up the flashover distance for the above voltage in Fig. 26. This distance is found to be 2·2 m and, therefore, because the physical clearance is only 2 m, bonding should be employed.

12.5.3 *Conditions Where Bonding is Needed*

In bonding adjacent metalwork to the lightning protective system, careful consideration should always be given to the possible effects such bonding might have upon metalwork which has been cathodically protected. The following points should be taken into account:

a) Where a structure contains electrically continuous metal (for example a roof, wall, floor, metal cladding or curtain walling), this metal may be used as a component of the lightning protective system provided that the amount and arrangement of the metal render it suitable for use as recommended in **12.1** to **12.4**.

b) Where a structure is simply a continuous metal frame, it requires no air termination or down conductor. It is sufficient to ensure that the conducting path is electrically and mechanically continuous and that the requirements of the code in respect of the connection to the general mass of the earth are met.

c) A reinforced concrete structure or a reinforced concrete framed structure may have sufficiently low inherent resistance to earth to provide protection against lightning and, if connections are brought out from the reinforcement at their highest points during construction a test may be made to verify this on completion of the structure (*see* Fig. 4).

   If the resistance to earth of the steel frame of the structure of the reinforcement of a reinforced concrete structure is found to be satisfactory, a horizontal air termination should be installed at the top and bonded to the steel frame or to the reinforcement (in the particular case of water cooling towers, it is not normal to fit an air termination. Where regular inspection is not possible, it is recommended that a corrosion resistant material be used for bonding to the steel or to the reinforcement and that this be brought out for connection to the air termination. Down conductors and earth terminations should, of course, be provided if the inherent resistance of the structure is found to be unsatisfactory when tested (*see* **12.3.1**).

d) Where metal exists in a structure and it cannot be bonded into a continuous conducting network, and which is not or cannot be equipped with external earthing connections, its presence should be disregarded. The danger inseparable from the presence of such metal can be minimized by keeping it entirely isolated from the lightning protective system; due consideration must be given to the recommendations of **12.5**.

e) Where the roof structure is wholly or partly covered by metal, care should be taken that such metal is provided with a continuous conducting path to earth.

f) In any structure, metal which is attached to the outer surface or projects through a wall or roof and has insufficient clearance from the lightning protective system, and is unsuitable for use as part of it, should preferably be bonded as directly as possible to the lightning protective system. If the metal runs close to an air termination network, for example water mains to storage tanks on roofs, cables, pipes, gutters, rainwater pipes, stairways, and runs approximately parallel to a down conductor or bond, it should be bonded at each end, but not below the test point. If the metal is in discontinuous lengths, each portion should be bonded to the lightning protective system; alternatively, where the clearances permit, the presence of the metal may be disregarded.

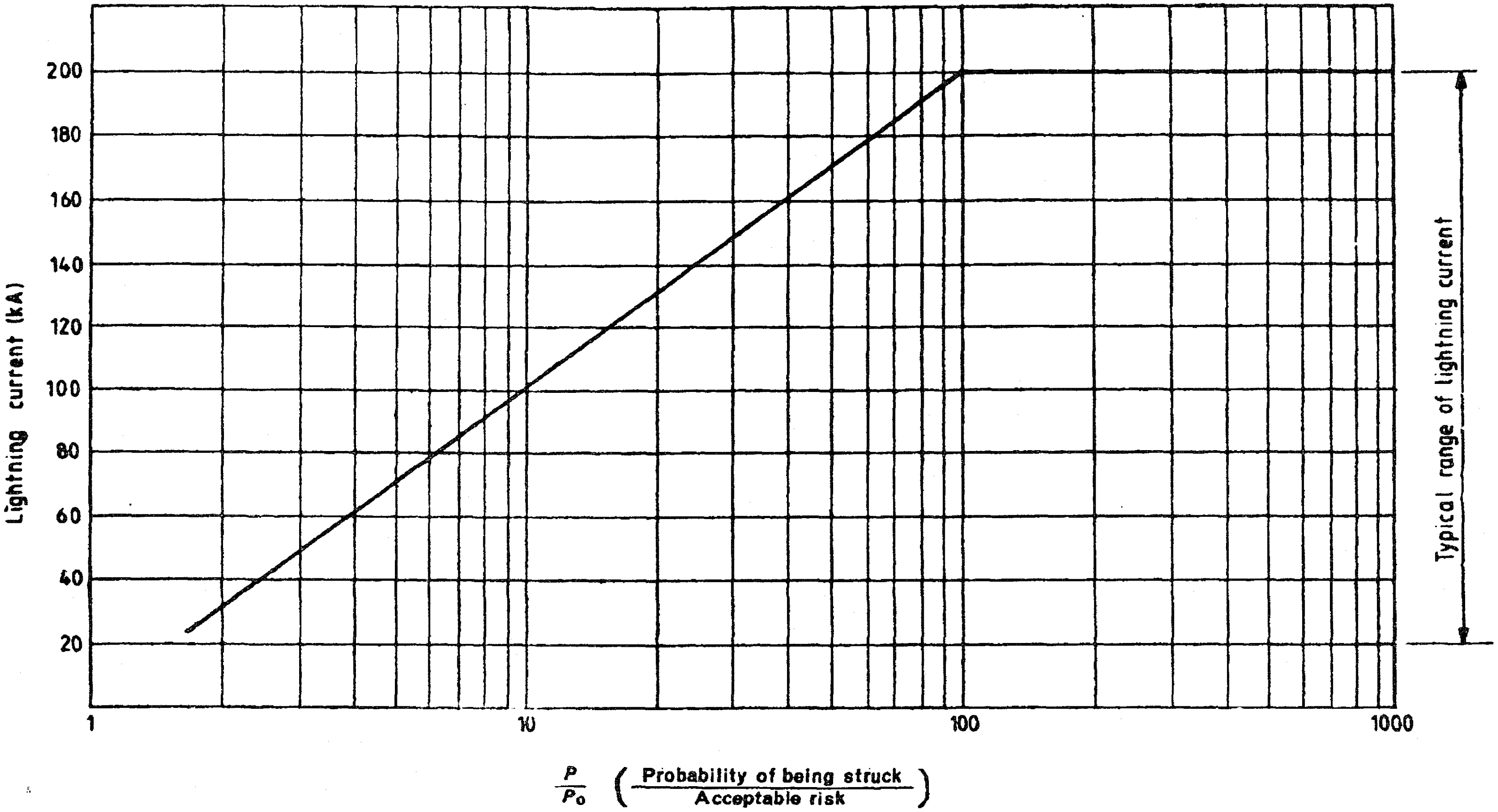


Fig. 25 Curve for Determining the Probable Maximum Current in the Lightning Flash from the Ratio P/P_0

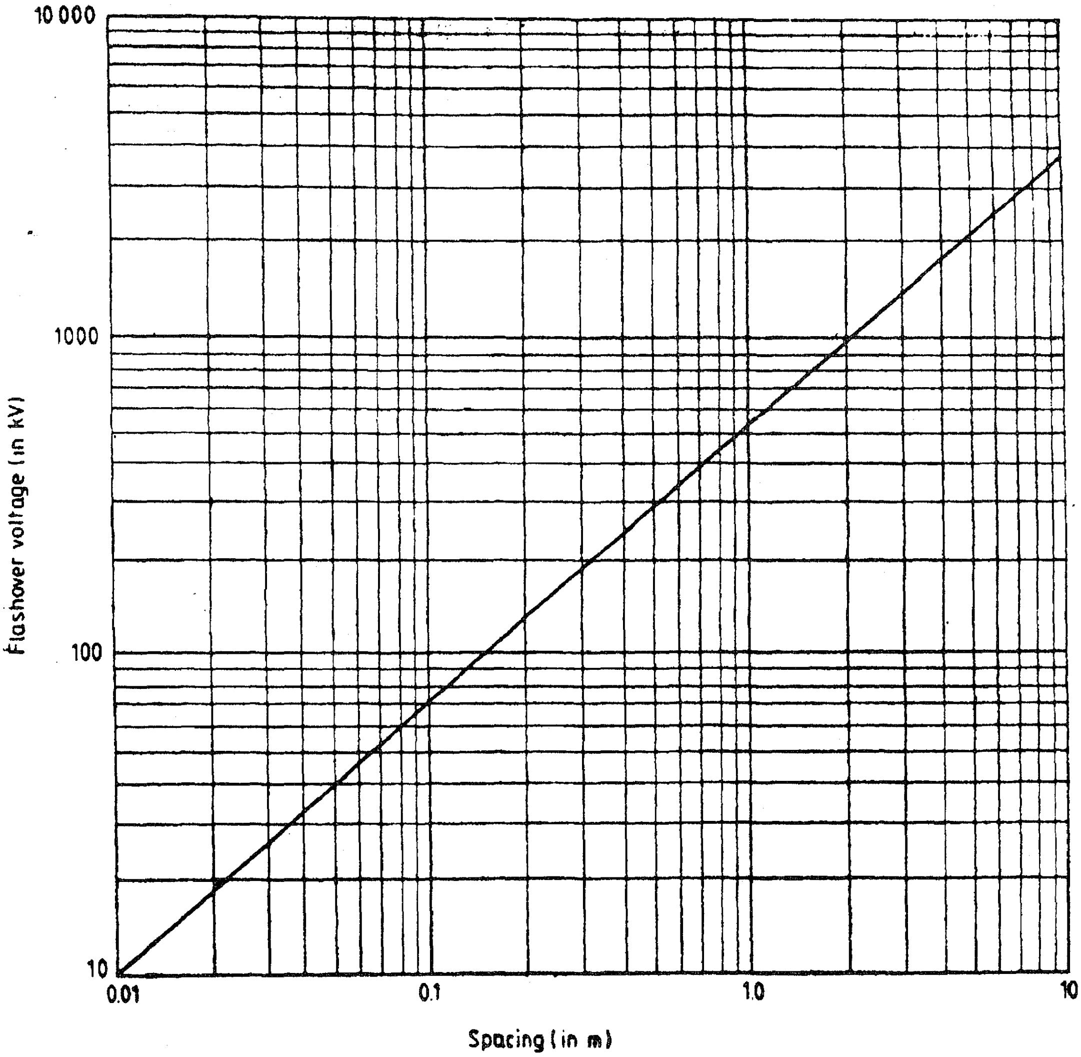


FIG. 26 CURVE FOR DETERMINATION OF THE FLASHOVER VOLTAGE IN AIR AS A FUNCTION OF SPACING

g) Masses of metal in a building, such as a bell-frame in a church tower, all clamped apparatus, equipment, which is connected to, or in contact with the mains water or electrical supplies, and/or which is itself earthed, if only by reason of the relevant code for electrical installations (*see* IS 732 : 1989) should be bonded to the nearest down conductor by the most direct route available.

h) Metal entering or leaving a structure in the form of sheathing, armouring or piping for electric, gas, water, rain, steam, compressed air, or any other service should be bonded as directly as possible to the earth termination. This should be done near to the point at which the service enters or leaves the structure.

No precise recommendations can be made because of the large variation in system designs. However, it should be noted that problems may arise where pipes/cables are protected with thermal or electrical insulation. In such cases bonding should be made to the nearest point where the metallic part of the pipe/cable becomes exposed. The bond should then be taken by as direct a route as practicable to the lightning earth outside the building.

This is more likely to apply in an insulated building to which the services are connected. However, where the building is surrounded by steel-work carrying an interconnected array of pipework, this in itself may well be a suitable point to which the earth connection should be made.

On the question of electricity supplies, the advent of CNE (Combined Neutral Earth) cables introduces problems whereby a fault in the neutral could result in the load current returning by way of the earth electrode. This would endanger anyone breaking the earth electrode circuit to make test measurements.

A typical system is shown in Fig. 27.

As a general rule, each system should be assessed on its merits and discussed with the authorities concerned.

j) Lift installation metalwork, together with all extended metal components on the inside and outside of a lift shaft, including ladders and handrails, must be bonded to the lightning conductor and to adjacent structural steel work (the steel frame or reinforcement), not only at the top and bottom of the lift shaft but at regular vertical intervals not exceeding 15 m (*see* Fig. 13).

13 CORROSION

13.1 General

Where corrosion due to atmospheric, chemical, electrolytic, or other causes is likely to impair any part of the lightning protective system, suitable precautions should be taken to prevent its occurrence.

13.2 Electrolytic Corrosion Between Dissimilar Metals

The contact of dissimilar metals, unless the contact surfaces are kept completely dry and protected against the ingress of moisture, is likely to initiate and accelerate corrosion.

Dissimilar metal contacts can exist where a conductor is held by fixing devices or against external metal surfaces. Corrosion can arise also where water passing over one metal comes into contact with another. Run-off water from copper, alloys, and lead can attack aluminium alloys and zinc. The metal of the lightning protective system should be compatible with the metal or metals used externally on the structure over which the system passes or with which it may make contact.

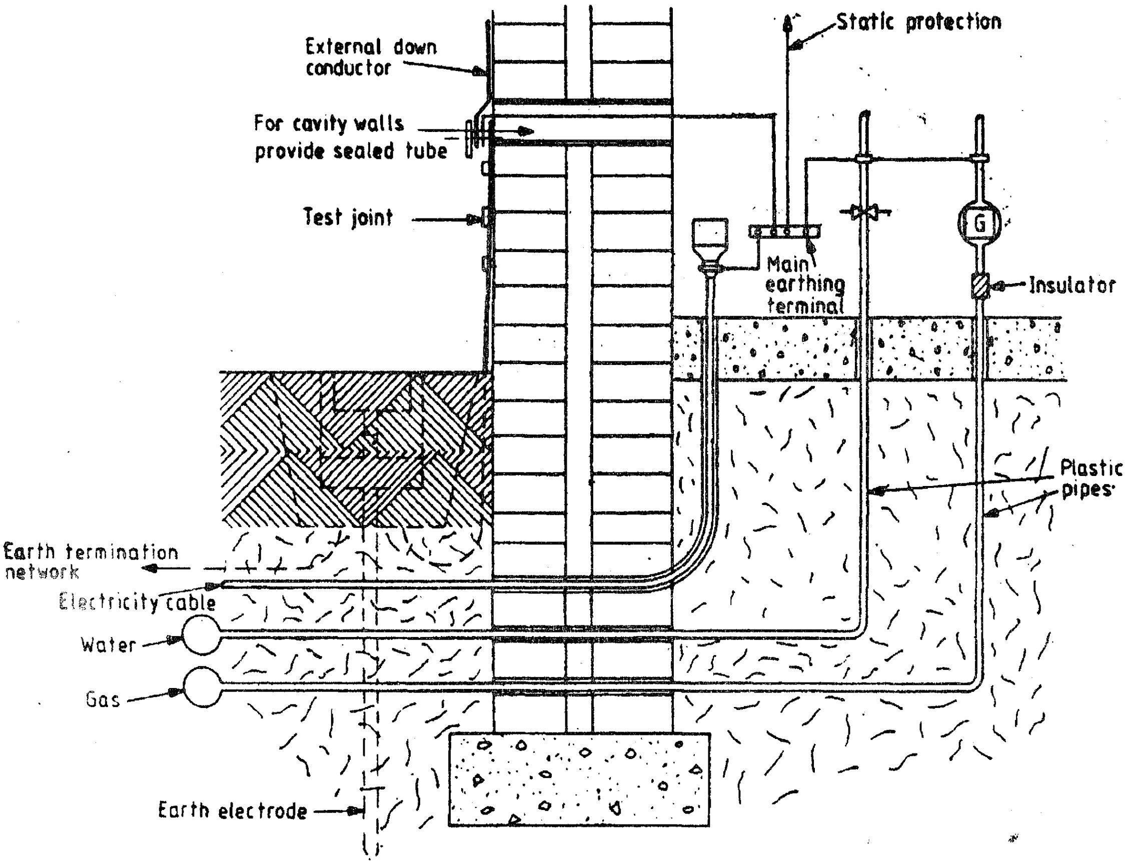
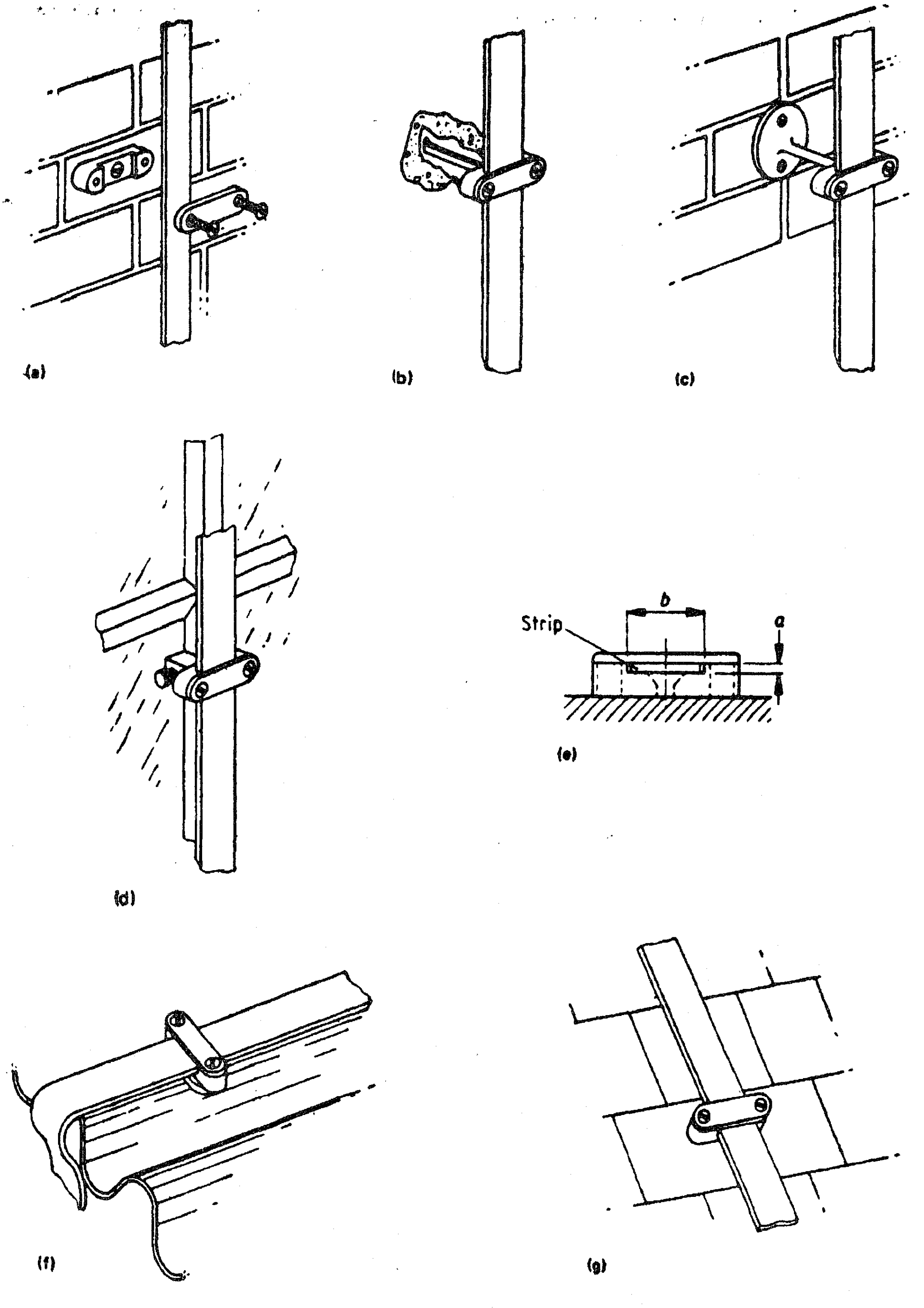


FIG. 27 DIAGRAM SHOWING BONDING TO SERVICES (GAS, WATER AND ELECTRICITY)



NOTES

1 Lightning conductor fixings should be purpose-made for each size of strip; dimension *a* in figure (e) should be equal to the thickness of the strip and *b* should be equal to the width plus 1·3 mm (for expansion). Conductors of circular section should be similarly treated.

2 All fixings should be securely attached to the structure; mortar joints should not be used.

FIG. 28 TYPICAL DESIGN FOR LIGHTNING CONDUCTOR FIXINGS

13.3 Chemical Corrosion of Aluminium Near Portland Cement, Mortar Mixes, etc

For a variety of reasons, aluminium is prone to corrosion when in contact with Portland cement and mortar mixes. For guidance on how to avoid this problem, the following recommendations on installation techniques are made:

a) Aluminium conductors should always stand off from any surface, particularly horizontal ones. This should avoid the conductors lying in water or being held in contact with corrosive materials, such as old mortar, etc. Suitable fixings are shown in Fig. 29.

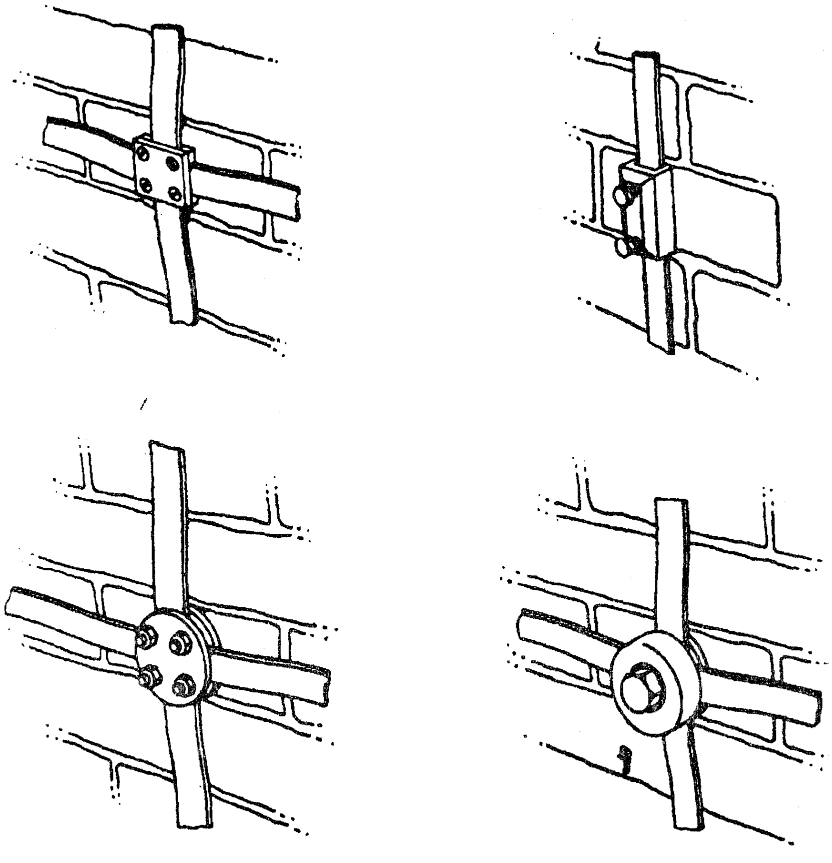
b) Conductors should not be positioned where they could become covered with debris, such as leaves, etc, or buried by soil. This should avoid the 'poultice problem' where any electrolyte tends to be held in continuous contact with the conductor.

c) The design of the clearing system should incorporate some form of drip-ring. This should help to prevent electrolyte, running off surfaces, being able to reach the conductor and run down it.

d) Where the above requirements cannot be satisfied, the conductor should be protected as recommended in **10** and consideration given to increasing its section.

13.4 Chemical Corrosion of Copper

Although copper is highly resistant to many types of chemical attack, lead coating is recommended where it is subject to severe corrosion from sulphur compounds. This is particularly the case where the location is inaccessible, for example at the tops of chimneys. The coating should be applied over the whole area likely to be under corrosive attack and should not be removed at joints. Insulating coatings which are not permanent or which are flammable are inadvisable. Fittings should be resistant to the corrosive agencies or be otherwise suitably protected. Joints and bonds may be protected with bitumen or embedded in plastic compound according to the local conditions (*see also* **10** and **12.2.4**).



NOTE — Corrosion inhibitor to be used on all joints and bonds.

Fig. 29 Test Joints

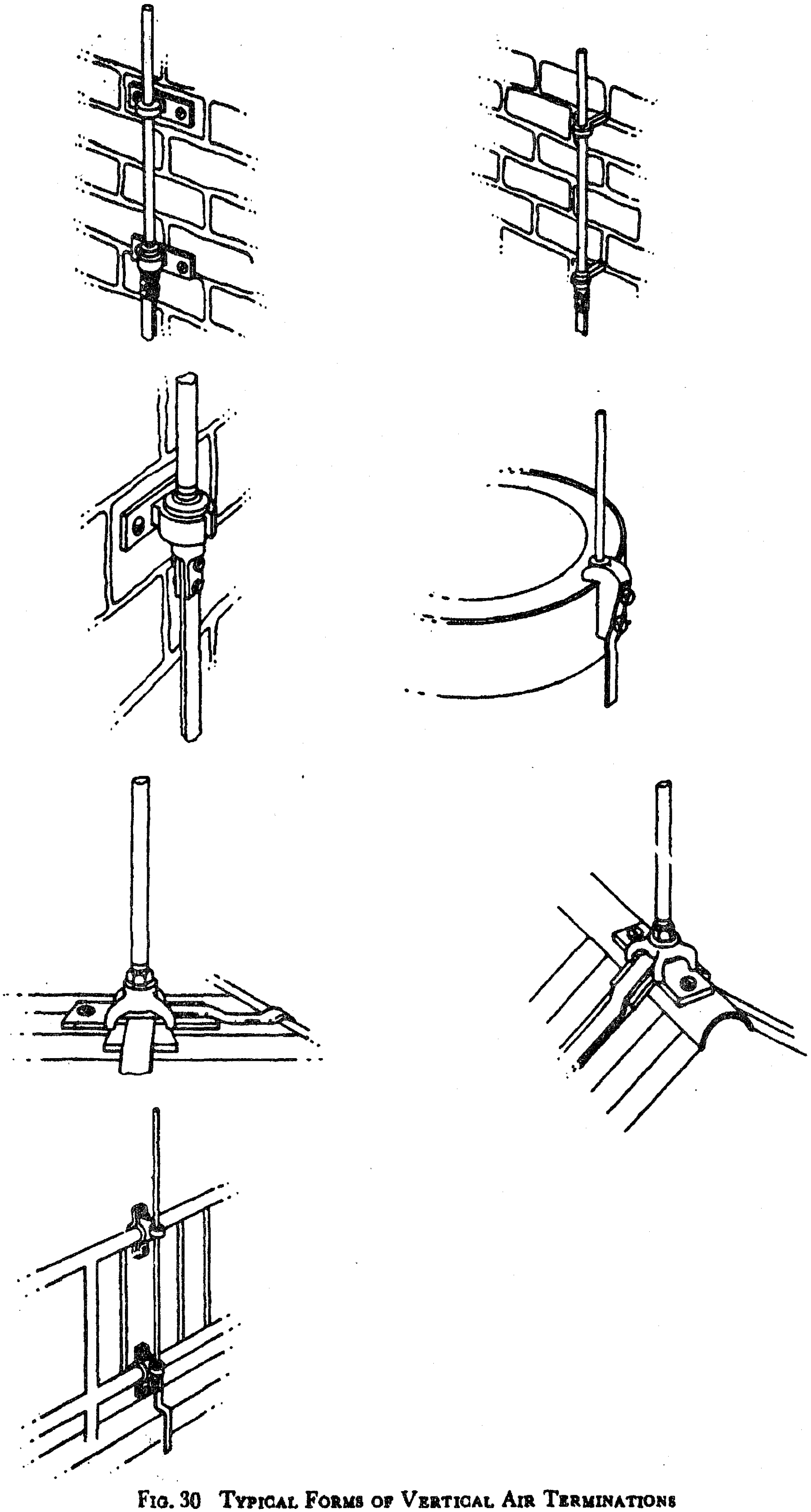


Fig. 30 Typical Forms of Vertical Air Terminations

SECTION 3 PROTECTION OF SPECIAL STRUCTURES

14 STRUCTURES EXCEEDING 30 m IN HEIGHT

14.1 Non-conducting Structures

On a non-conducting structure, for example, a church spire, other than those chimneys which are very high compared with their breadth, a single down conductor is adequate provided that the air termination gives the desired zone of protection.

A non-conducting chimney of which the overall width of the top exceeds 1·5 m should have at least two equally-spaced down conductors, bonded by a metal cap or by a conductor around the top of the chimney (*see* Fig. 12).

14.2 Conducting Structures

The recommendations in the second paragraph of 12.5.3(c) are equally applicable to tall conducting structures but, where down conductors are needed, not less than two should be installed and these should be spaced at not more than 15 m apart around the perimeter.

14.3 All Types of Structure

Both non-conducting and conducting structures which are supported by stay-wires should be dealt with as described in **14.1** and **14.2** but, in addition, the upper ends of the stay-wires should be bonded to the lightning protective system and the lower ends earthed.

14.4 Further guidance can be had from **27.2**.

15 STRUCTURES WITH ROOFS OF HIGH FLAMMABILITY

15.1 Air Terminations

On structures having roofs of straw, reed, grass, or other highly combustible material, a suspended air termination with a clearance of at least 0·3 m to the roof may be suspended from non-conducting and non-combustible supports or, alternatively, the air termination conductor may be laid on a hardwood strip 75 mm wide. Where wire netting is used to protect thatch and similarly-constructed roofs against wind and birds, it should not form part of the lightning protective system.

15.2 Conductors and Bonds

Conductors or bonds which unavoidably penetrate the roofing material should be taken through non-conducting and non-combustible sleeves.

16 BUILDINGS WITH EXPLOSIVE OR HIGHLY FLAMMABLE CONTENTS

16.1 General

Problems arising in the provision of lightning protective systems for these structures are preferably dealt with by specialists conversant with any relevant Statutory Regulations and codes of practice.

An acceptable risk may be present when the quantity of dangerous material is strictly limited, as in a laboratory or small store, or where the structure is sited in an isolated position or specifically designed to restrict the effects of a catastrophe. Circumstances may also arise in which the dangerous materials are not exposed but are completely encased in metal of an adequate thickness. Under these conditions, lightning protection may not be required at all. In other situations, the risk to life and property may be so patently obvious that the provision of every means possible for protection from the consequences of a lightning discharge is essential. Accordingly, recommendations for such cases are set out in this clause and are applicable to structures in which explosive or highly-flammable solids, liquids, gases, vapours, or dusts are manufactured, stored or used, or in which highly-flammable or explosive gases, vapours or dusts may accumulate.

16.2 Protective Methods

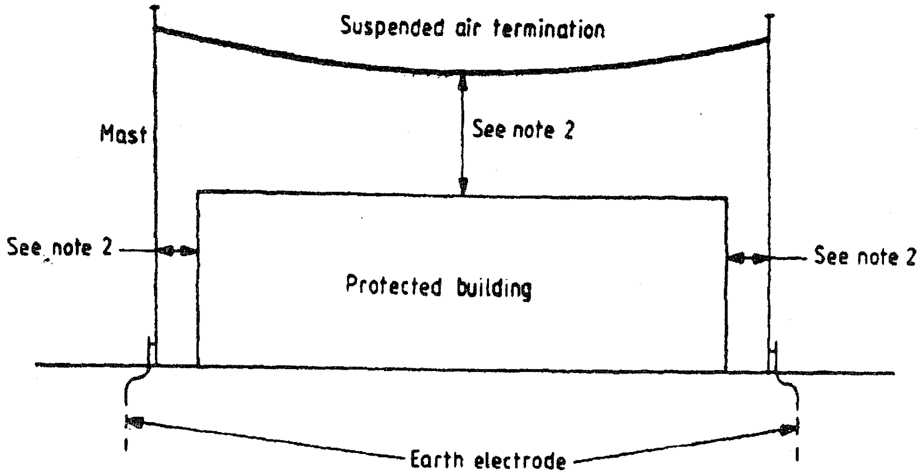
16.2.1 *Suspended Air Terminations*

An air termination network should be suspended at an adequate height above the area to be protected. If one horizontal conductor only is used, the protective angle adopted should not exceed 30° (*see* Fig. 15). If two or more parallel horizontal conductors are installed, the protective angle to be applied may be as much as 45° within the space bounded by those conductors, but it should not exceed 30° outside that space (*see* Fig. 31). The heights of the horizontal conductor(s) should be chosen according to the recommendations of **12.5.2**; in cases of doubt, expert advice should be sought. The supports of the network should be adequately earthed.

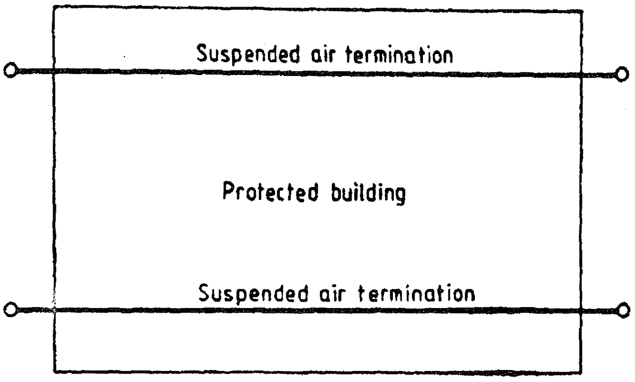
Alternatively, where the expense of the preceding method would be unjustified, and where no risk would be involved in discharging the lightning current over the surface of the structure to be protected, either of the following arrangements would be suitable:

a) A suspended air termination as shown in Fig. 28, but where protection angles are deemed to be 45° instead of 30°, and 60° instead of 45°.
b) A network of horizontal conductors with a mesh between 3 m and 7·5 m, according to the risk, should be fixed to the roof of the structure (*see* Fig. 32).

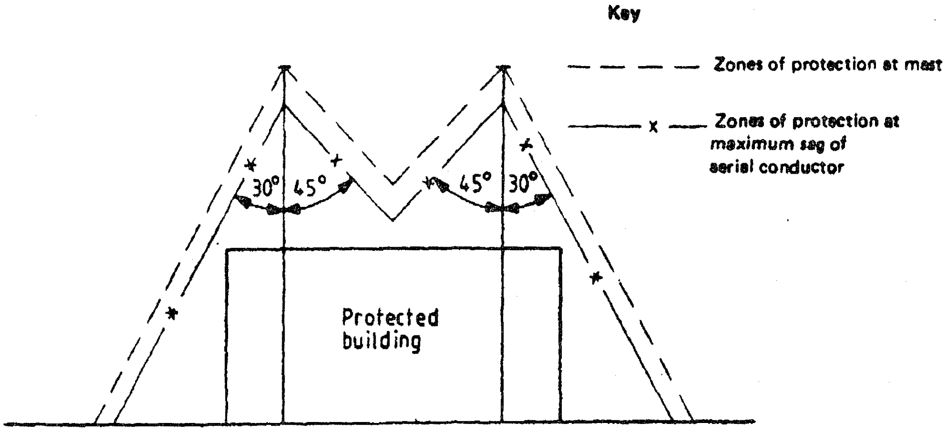
NOTE — Each separate structure protected in this alternative way should be equipped with twice the number of down conductors recommended in **12.4**.



(a) Elevation



(b) Plan


Key
Zones of protection at mast
x Zones of protection at maximum sag of aerial conductor
30°
45°
45°
30°
Protected building

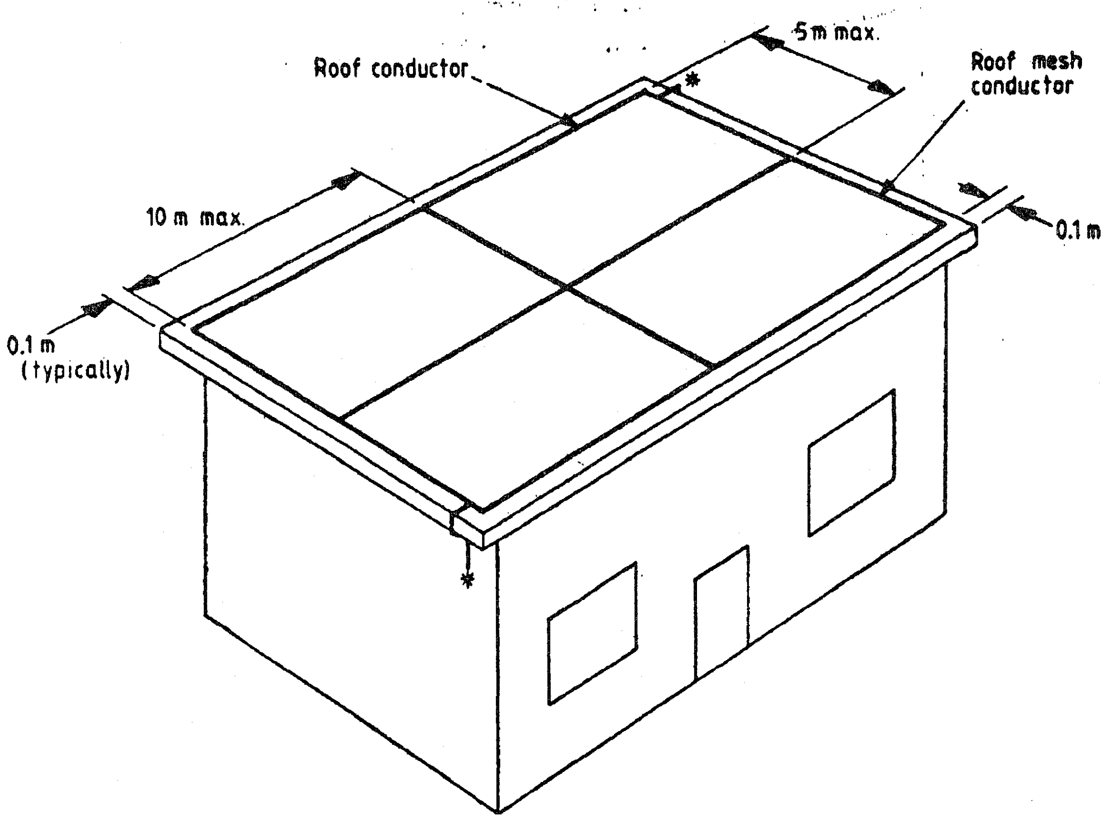
(c) End elevation showing zones of protection

NOTES

1 Where two or more suspended horizontal conductors are employed, a protective angle of 45° may be used in the space bounded by the conductors. Elsewhere the protective angle is limited to 30°.

2 To prevent flashover between mast/conductor and protected building, the minimum clearance distance has to be 2 m or as governed by 15.5.2, whichever is the greater. This clearance has to be as above under maximum sag conditions, i.e. snow and ice on aerial conductor.

FIG. 31 AIR TERMINATION WITH TWIN SUSPENDED HORIZONTAL CONDUCTORS AND ZONE OF PROTECTION FOR STRUCTURE WITH EXPLOSIVE OR HIGHLY FLAMMABLE CONTENTS



NOTES

1 The horizontal conductor mesh size should be 5 m × 10 m or smaller, according to the risk.

2 For clarity down conductors are omitted.

*Represents a bond to roof steelwork.

FIG. 32 AIR TERMINATION NETWORK WITH HORIZONTAL CONDUCTORS FOR STRUCTURE WITH EXPLOSIVE OR HIGHLY FLAMMABLE CONTENTS

16.2.2 *Vertical Conductors*

A structure or a group of structures of small horizontal dimensions may be protected by one or more vertical lightning conductors. If one lightning conductor is used, the protective angle adopted should not exceed 30°. If two or more lightning conductors are installed, the protective angle to be used may be 45° within the space bounded by the conductors, but it must not exceed 30° outside that space. Examples of this method of protection are illustrated in Fig. 33.

16.2.3 *Partially Buried or Buried Structures*

16.2.3.1 A structure which is partially buried or mounded would be protected in a similar manner to a structure standing above ground.

16.2.3.2 A structure which is wholly below ground and which is not connected to any service above ground can be protected by an air termination network as in **16.2.3.1**, complete with its earth termination network. The impulse breakdown strength of the soil can be taken into account when determining the risk of flashover from the protective system to the structure to be protected, including its services. Where the depth of burying is adequate, the air termination network may be replaced by a network of earthing strips arranged on the surface in accordance with expert advice. Where this method is adopted, the bonding recommendations (*see* **16.2.4, 16.2.5** and **16.2.6**) for metal in, or metal conductors entering the structure, should be ignored.

16.2.4 *Ring Conductors*

The earth terminations of each lightning protective system should be interconnected by a ring conductor. This ring conductor should preferably be buried to a depth of at least 0·5 m unless other considerations, such as the need for bonding other objects to it or testing, make it desirable to leave it exposed. The ring conductor should be connected to the ring conductors of the neighbouring structures.

16.2.5 *Metal on or in the Structure*

16.2.5.1 All major metal forming part of the structure, including continuous metal reinforcement and services, should be bonded together and connected to the lightning protective system. Such connections should be made in at least two places (*see* Fig. 9) and should, wherever possible, be equally spaced around the perimeter of the structure at intervals not exceeding 15 m.

16.2.5.2 Metalwork inside the structure should be bonded to the lightning protective system.

16.2.6 *Electrical Conductors Entering a Structure*

16.2.6.1 Electrical conductors entering a structure of this category should be metal-cased. This metal casing should be electrically continuous within the structure; it should be earthed at the point of entry inside the structure on the user's side of the service and bonded directly to the lightning protective system (*see* Fig. 27). The agreement of the operating authority or owner of the cables to the proposed bonding arrangements should be obtained.

16.2.6.2 Where the electrical conductors are connected to an overhead electricity supply line, a 15 m length of buried armoured cable should be inserted between the overhead line and the point of entry to the structure (*see* Fig. 34). Attention should be given to any Statutory Regulations and Codes of Practice which are applicable (*see also* **19**).

NOTE — Overhead supply lines are liable to have large surges induced in them from lightning discharges. Some form of surge suppression is, therefore, needed where they join the buried cable. This will allow a large part of the lightning current to be discharged to earth at a safe distance from the structure.

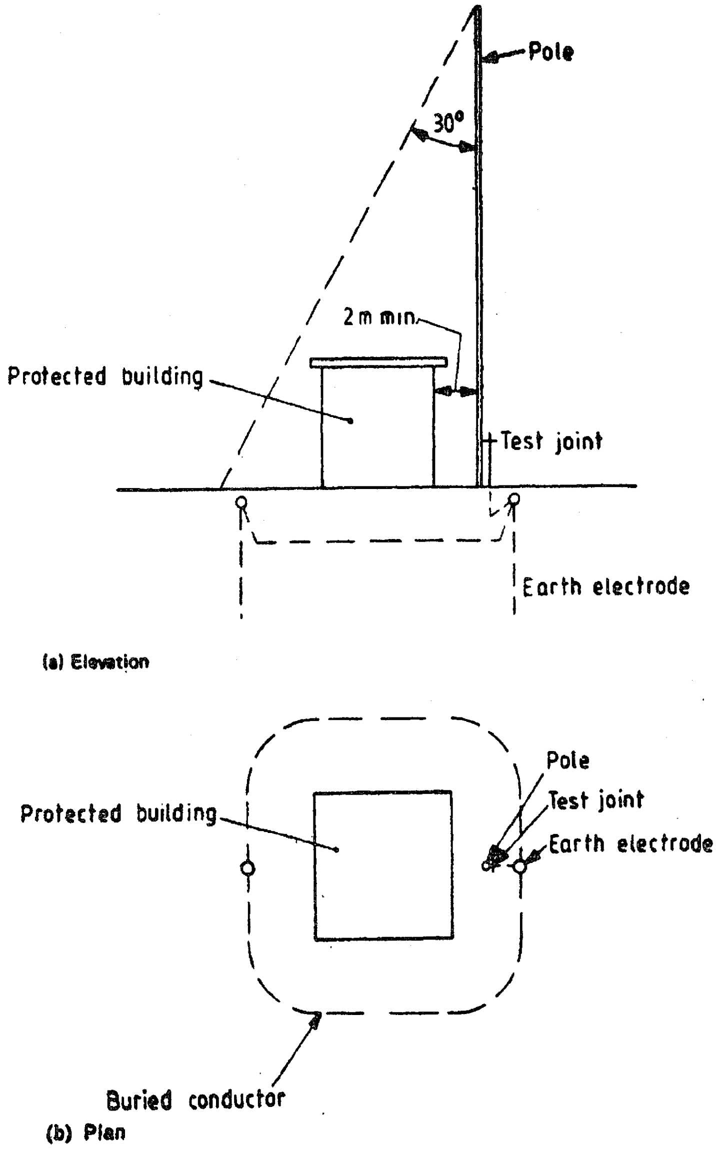


Fig. 33 Vertical Air Termination for Protection of Explosives Stores

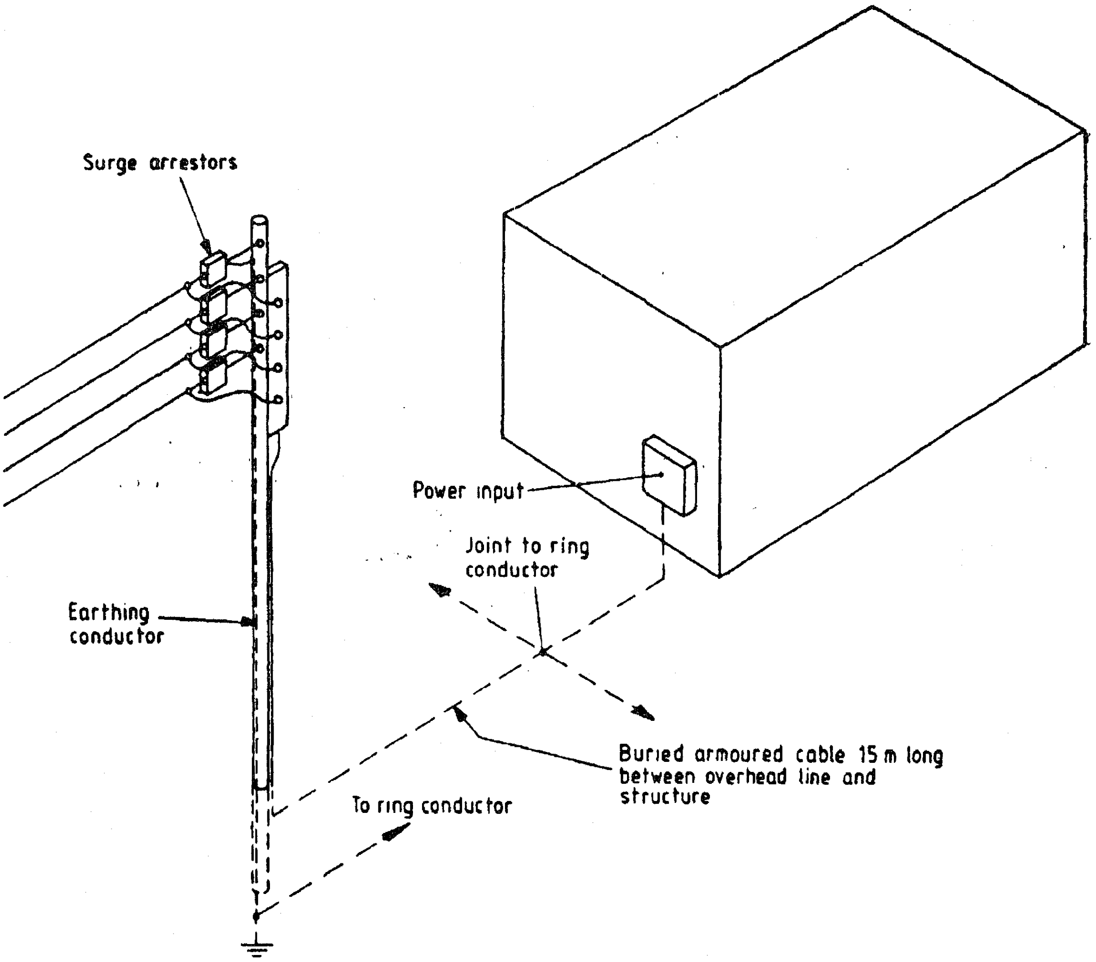


FIG. 34 EXCEPTIONAL PROTECTION AGAINST OVERVOLTAGES INDUCED BY LIGHTNING IN INCOMING SUPPLIES TO BUILDINGS WITH EXPLOSIVE OR HIGHLY FLAMMABLE CONTENTS

16.2.7 *Pipes, Rails, etc, Entering a Structure*

With the exception of CNE cables, metallic pipes, electrical conductor sheaths, steel ropes, rails, railway tracks, or guides not in continuous electrical contact with the earth, which enter a structure of this kind should be bonded to the lightning protective system. They should be earthed at the point of entry outside the structure and at two further points, one about 75 m away and one a further 75 m away.

16.2.8 *Adit or Shaft Entrance to Structures*

For a buried structure or underground excavation to which access is obtained by an adit or shaft, the recommendations in **16.2.7** as regards extra earthing should be followed for the adit or shaft at intervals not exceeding 75 m within as well as outside the structure.

16.2.9 *Fences, Retaining Walls, etc* (*see also* **17**)

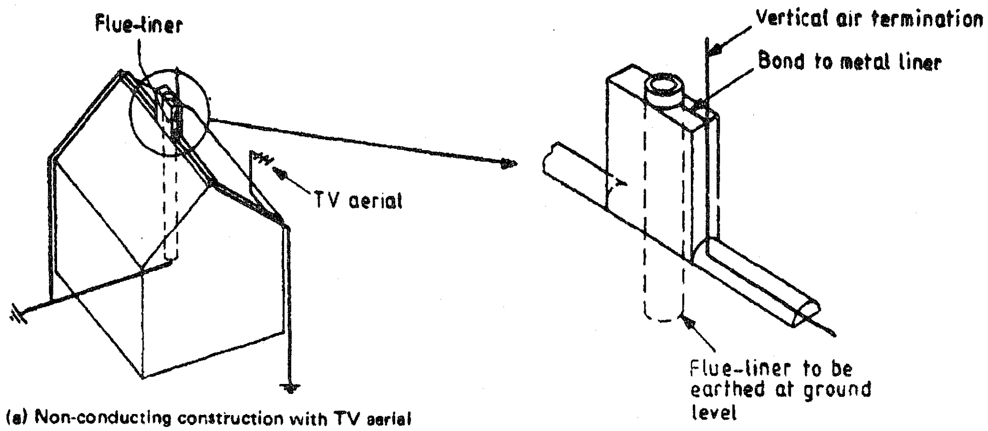
The metal uprights, components and wires of all fences, and of retaining walls within 2 m of the structure, should be connected in such a way as to provide continuous metallic connection between them and the lightning protective system.

16.2.10 *Vents*

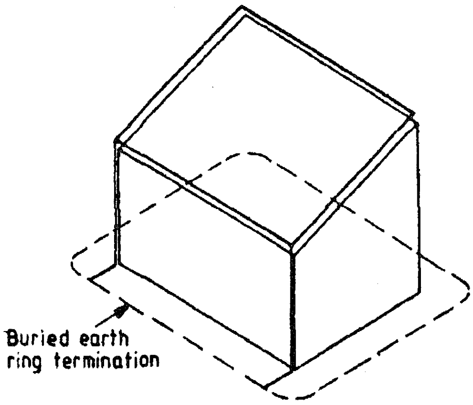
The vents of any tanks containing flammable gas or liquid and exhaust stacks from process plants emitting flammable vapours or dusts should either be of non-conducting material or be fitted with flametraps.

16.2.11 *Danger from Tall Components on or Near High Risk Structures*

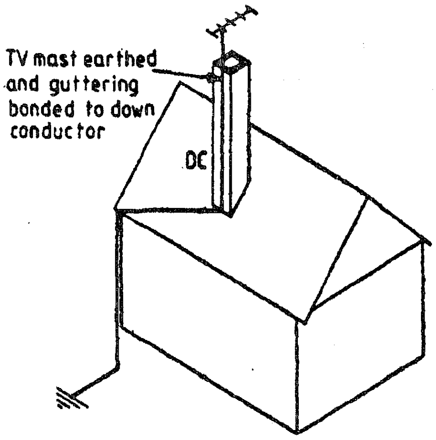
Structures of this category should not be equipped with tall components such as spires and flagmasts or radio aerials on the structure or within 50 m of the structure. The clearance applies also to the



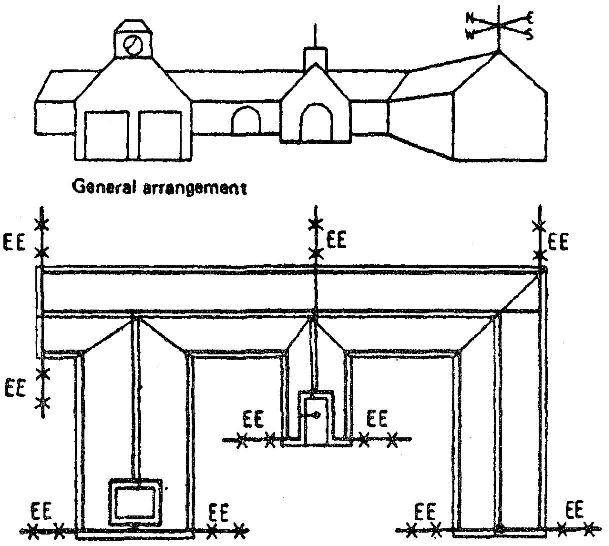
(a) Non-conducting construction with TV aerial in roof space and services (internal) bonded to down conductors



(b) Non-conducting construction built on rocky ground showing earth ring termination



(c) Stone construction with TV mast (external) earthed and guttering bonded to down conductor



General arrangement

Plan showing typical protection system

Key
EE Earth electrodes

NOTE. See also the following:

bond to water supply 18.3.9;
bond to electricity supply 18.3.9;
bond to weather vane clause 19;
down conductors and earths clauses 15 and 16;
air terminations clause 14.

(d) Large isolated and exposed property

Fig. 35 Lightning Protection for Domestic Properties

planting of new trees, but structures near existing trees should be treated in accordance with the recommendations of **18**.

16.2.12 *Safe Testing*

Testing should be carried out in accordance with the recommendations of 23 and the test equipment should be of a type which is intrinsically safe for the particular hazard.

17 FENCES

17.1 Nature of Danger

If an extended metal fence is struck, the length between the point of strike and the nearest earth termination is raised momentarily to a high potential relative to that of the earth. Person or livestock in close proximity to, or in contact with such fencing at the time of a lightning discharge to the fencing may, therefore, be exposed to danger. It is desirable, therefore, to earth the fence via earth electrodes at intervals in order to discharge the lightning as effectively as possible.

Ideally, the continuity of the fence should be broken by gaps along its length filled with insulating sections. This would help to restrict the effect of the lightning strike to the particular section struck. However, where fences are primarily used for security reasons, the inclusion of insulating sections raises other problems.

Recommendations are made below.

17.2 Protection of Livestock in Fields

17.2.1 *General*

The loss of livestock by lightning during thunderstorms is due mainly to herds congregating under trees in open fields or drifting against unearthed wire fences and receiving a discharge sufficient to kill them. Whereas the nature of the exposure of livestock in fields is such that it is not possible to eliminate the hazard entirely, the taking of the following precautions will reduce the hazard to some extent.

17.2.2 *Earthing*

Where fences are constructed of metal uprights and continuous electrically conducting wires, for example, barbed wire, strained wires, chain link, each continuous wire should be bonded to the metal uprights at intervals. In cases where wooden or concrete posts are used, bonding should be to earth electrodes, for example, driven rods.

The intervals between bonding should not exceed 150 m where the soil is permanently wet and should be reduced to 75 m in dry soil.

17.2.3 *Insulated Gaps*

The continuity of the metal fence should be broken at intervals not exceeding 300 m by wooden gates or by gaps not less than 600 mm wide closed by sections of non-conducting material.

NOTE — The use of plastic covered chain link fencing is not recommended for such closing sections.

The earth termination of the fence at such a gap should be at least 8 m away from either side of the gap.

17.3 Fences Surrounding Structures Containing Flammable Liquids or Gases

17.3.1 *Earthing of All Metal Fences*

Where fences which surround hazardous locations are of the all-metal type, no particular problems arise, and they can be earthed as described in **17.2.2**, but at intervals not exceeding 75 m.

17.3.2 *Earthing of Plastic-Coated Fences*

Much of the fencing in current use is of the plastic-coated close-mesh steel wire type.

The plastic coating provides weather protection and breaking through it in order to earth the metal would increase the risk of corrosion and is not, therefore, recommended.

This type of fencing, however, normally carries a run of barbed wire at high level. It is recommended that this wire should be earthed at intervals not exceeding 75 m in order to act as an air termination for the protection of the fence.

17.3.3 *Insulated Gaps*

Because these fences are primarily for security purposes, insulated gaps may breach security requirements and are, therefore, not recommended. Where the security fence separates grazing land from a hazardous or high security area, a balance must be struck between the attendant risks in each case.

18 TREES AND STRUCTURES NEAR TREES

18.1 The protection of trees against the effects of lightning need be considered only where the preservation of the tree is especially desirable because of its historical, botanical, environmental or other similar value. For such cases the following recommendations are made:

a) A main down conductor should be run from the topmost part of the main stem to the earth termination should be protected against mechanical damage at ground level.

b) Large upper branches should be provided with branch conductors bonded to the main conductor.

c) Conductors so used should be stranded and, if copper, should be insulated so as not to poison the tree. The total cross-sectional area should not be less than 70 mm^2 for copper and aluminium. No precise sizes are given because this causes problems of availability. The important point is that the conductors should be flexible.

d) In the fixing of the conductors, allowance should be made for swaying in the wind and the natural growth of the tree.

e) The recommendations of **12.2.7** need not be taken into account.

f) The earth termination should consist of two rods driven into the ground on opposite sides of, and close to, the trunk of the tree. A strip conductor should be buried encircling the roots of the tree at a minimum distance of 8 m radius from the centre of the tree or at a distance of not less than 600 mm beyond the spread of the foliage, whichever is the greater. This conductor should also be bonded to the rods by two radial conductors. The earth termination and resistance should satisfy the recommendations of **12.3**.

g) Where two or more trees are so close together that their encircling earth conductors would intercept, one conductor adequately connected to the earth rods should be buried so as to surround the roots of all the trees.

h) Where an isolated tree stands close to a structure, its presence can be disregarded if its height does not exceed that of the structure. If the tree is taller than the structure, the following clearances between the structure and the tallest part of the tree may be considered as safe:

   1) For normal structures, half the height of the structure; and

   2) For structures for explosive or highly flammable contents, the height of the structure.

18.2 If these clearances cannot be ensured, the extent of the risks involved should be considered. To reduce the risks to the minimum, when the tree is to remain, the structure would have to be protected in accordance with the recommendations of this Code and the air termination or down conductor should be arranged so as to pass as close as possible to the nearest part of the tree.

NOTE — When a tree is left unprotected, a lightning current discharged into it can be conducted over distances of many tens of metres, along or just under the surface of the ground in order to find a good conductor, for example, a water or gas pipe, electricity cable, or the lightning protective earth of building.

18.3 Further guidance can be had from **27.3**.

19 STRUCTURES SUPPORTING OVERHEAD ELECTRICITY SUPPLY, TELEPHONE AND OTHER LINES

19.1 If any overhead electricity supply lines, telegraph or telephone wires or radio and television relay service on metal supports fixed to structures, the supports should where practicable be earthed and also bonded to a lightning protective system.

19.2 On structures at which service supply lines terminate, a surge protective device should be connected between the electricity conductor or conductors and an earthed point.

Permission for these measures should be sought from the owners of the lines.

20 STRUCTURES WITH RADIO AND TELEVISION AERIALS

20.1 Indoor Aerials in Protected Structures

Structures protected against lightning in accordance with the recommendations of this Code may be equipped with indoor radio and television receiver aerials without further precautions, provided the clearance between the aerial system, including the down leads or feeders, and the external lightning protective system accords with the values given in **12.5**.

20.2 Outdoor Aerials on Protected Structures

Structures protected against lightning in accordance with the recommendations of this Code may be equipped with outdoor radio and television aerials without further precautions, provided that every part of the aerial system, including any supporting metal work, is within the zone of protection of the lightning protective system.

Where the conditions in the preceding paragraph cannot be fulfilled, precautions should be taken to ensure that the lightning current can be discharged to earth without damage to the structure and its occupants as given below:

a) With an aerial system fitted directly on to a protected structure this can be accomplished by connecting the aerial bracketry to the lightning protective system at the nearest point accessible below the aerial installation.

b) With an aerial system fitted on a metallic support structure which projects above the lightning protective system this can be accomplished by connecting the aerial support structure to the lightning protective system at the nearest point accessible below the aerial installation.

20.3 Aerials on Unprotected Structures

Before installing an aerial on an unprotected structure, the need to provide a protective system should be assessed in accordance with the detail in **8.1**.

20.4 Use of Earth Electrodes of Lightning Protective System

It is permissible to use the earth electrode of the lightning protective system for the purposes of earthing the aerial system, provided this does not conflict with the regulations for the reception of sound and television broadcasting.

21 MISCELLANEOUS STRUCTURES

21.1 Tents

21.1.1 *Large Tents*

Where large temporary structures of this type are used for such purposes as exhibitions and entertainments involving large numbers of people, consideration should be given to their protection against lightning. In general, such structures are manufactured from non-metallic materials and the simplest form of protection will usually consist of one or more horizontal air terminations suspended above them and connected solidly to earth. A non-metallic extension of the vertical supports provided for such structures may, if convenient and practicable, be used for supporting a system of horizontal air terminations but a clearance of not less than 1·5 m should be maintained between the conductor and the fabric of the enclosure. Down conductors should be arranged outside the structure and be connected to earthing rods which in turn should be connected to a ring conductor in such a manner as to be inaccessible to the general public. Those types of structure which have metal frameworks should have these efficiently bonded to earth at intervals of not more than 30 m of the perimeter.

21.1.2 *Small Tents*

For small tents no specific recommendations can be given but some of the problems involved are considered in **27.4**.

21.2 Metal Scaffolding and Similar Structures

Where such structures are of sufficient size to warrant protection and are readily accessible to the general public, particularly where they are erected over and on part of the common highway, or as may be used in the construction of public seating accommodation, they should be efficiently bonded to earth. A simple method of bonding such structures consists of running a strip of metal, other than aluminium, 20 × 3 mm in size, underneath and in contact with the base plates carrying the vertical numbers of the scaffolding and earthing it at intervals not exceeding 30 m. With public seating accommodation, only the peripheral members of the structure need bonding to earth. Other steel structures, such as those used for pedestrian bridges over main trunk roads, are frequently sited in isolated situations where they may be prone to lightning strokes and should, therefore, be bonded to earth, particularly at the approach points.

21.3 Tall Metal Masts, Tower Cranes, and Revolving and Travelling Structures

Masts and their guy wires, floodlighting towers, and other similar structures of metallic construction should be earthed in accordance with the recommendations of this Code.

Cranes and other tall lifting appliances used in building construction, in shipyards, and in port installations also require bonding to earth. For cranes or revolving structures mounted on rails, efficient earthing of the rails, preferably at more than one point will usually provide adequate lightning protection. In special cases, where concern is felt regarding possible damage to bearings by lightning, additional measures may be justified and expert advice should be sought.

21.4 Farm Buildings in Areas of High Lightning Incidence

In some areas, where lightning incidence is high but where the use of copper or aluminium would be economically unjustifiable or be otherwise inadvisable, galvanized mild steel wire may be used for the protection of small farmsteads or similar structures. It should consist of a single strand, not less than 6 mm in diameter erected to span the roof and ends of the structure and to continue into the ground at a depth of 0·5 m for a distance of 3 m (Fig. 36). Supports may be timber, arranged to provide a clearance of not less than 0·9 m from the roof. Test joints are not required as tests after installation, and subsequently, are improbable. However, as deterioration is likely to occur first in the buried portions, a short separate length of similar material to the lightning conductor, suitably pointed and galvanized overall, should be inserted in the ground beside each earth termination to permit periodic withdrawal, visual examination and reinsertion to serve as an indication of the condition of the underground conductor material. Means should be provided to prevent access to the exposed conductor and the ground in the immediate vicinity of the buried metal.

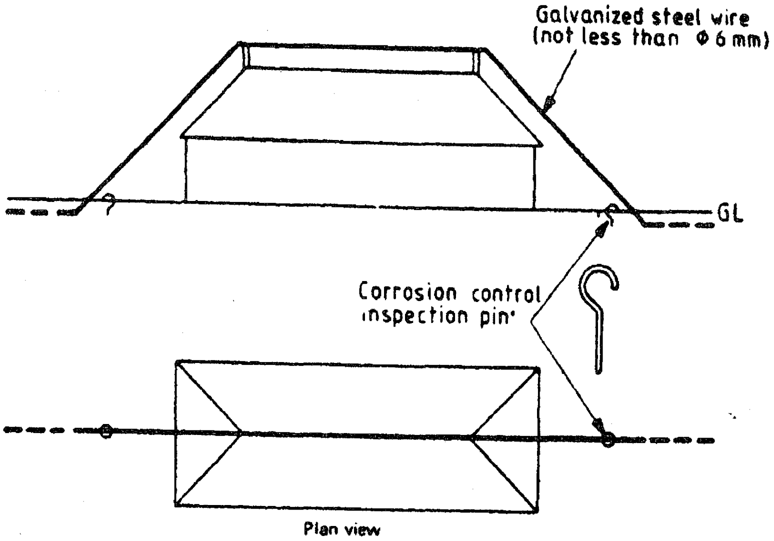

Galvanized steel wire (not less than Φ 6 mm)
GL
Corrosion control inspection pin
Plan view

FIG. 36 LIGHTNING PROTECTION (LOW COST INSTALLATION) FOR ISOLATED FARM BUILDINGS OF BRICK AND TILE CONSTRUCTION

21.5 Sports Stadiums

Large sports stadiums are usually occupied for only a small percentage of the time. Nevertheless, large number of people are often involved and some measure of protection may be considered necessary.

With the advent of high multi-tier stands, air terminations in the form of horizontal wires could be strung across the stadium from one side to the other. Bonding of all metal parts would need to be done in accordance with the recommendations of this Code.

Another possibility would be to make use of the floodlighting towers, either as essential elements of the lightning protective system or as supports for horizontal wires. In either case provision would need to be made to protect people from danger by direct contact with the towers or against ground voltage stress around their bases. Direct contact with the tower could be prevented by sheathing with a protective insulating material from ground level to a height of about 3 m or by fencing off the tower base and restricting access to it.

On the matter of reducing ground stress to a level which would not cause harm to human beings, this would depend upon the average soil resistivity and the earthing arrangements. Some general comments are given in **27.4.3** but it will often be desirable to seek specialist advice (*see also* Fig. 17 and 37).

21.6 Raised Motorways, Bridges, etc

Simple calculations show that side flashing is more likely to occur when standing under the edge rather than on the centre-line of the roadway, mid-way between the supporting pedestals. In the above case, the following recommendations are suggested (*see* Fig. 38):

a) Bond the lighting structure, railings, etc, to the reinforcing bars and do *NOT* use a separate down conductor, mounted externally.

b) In potentially dangerous areas where people are known to group, put up warning notices about the dangers of standing near the edge with umbrellas raised.

21.7 Dwelling Houses

The recommendations of Code are applicable to dwelling houses. The protection of buildings with television and radio aerials is discussed in **20**, where protection is provided. The recommended practice for dealing with metallic flue liners is shown in Fig. 35.

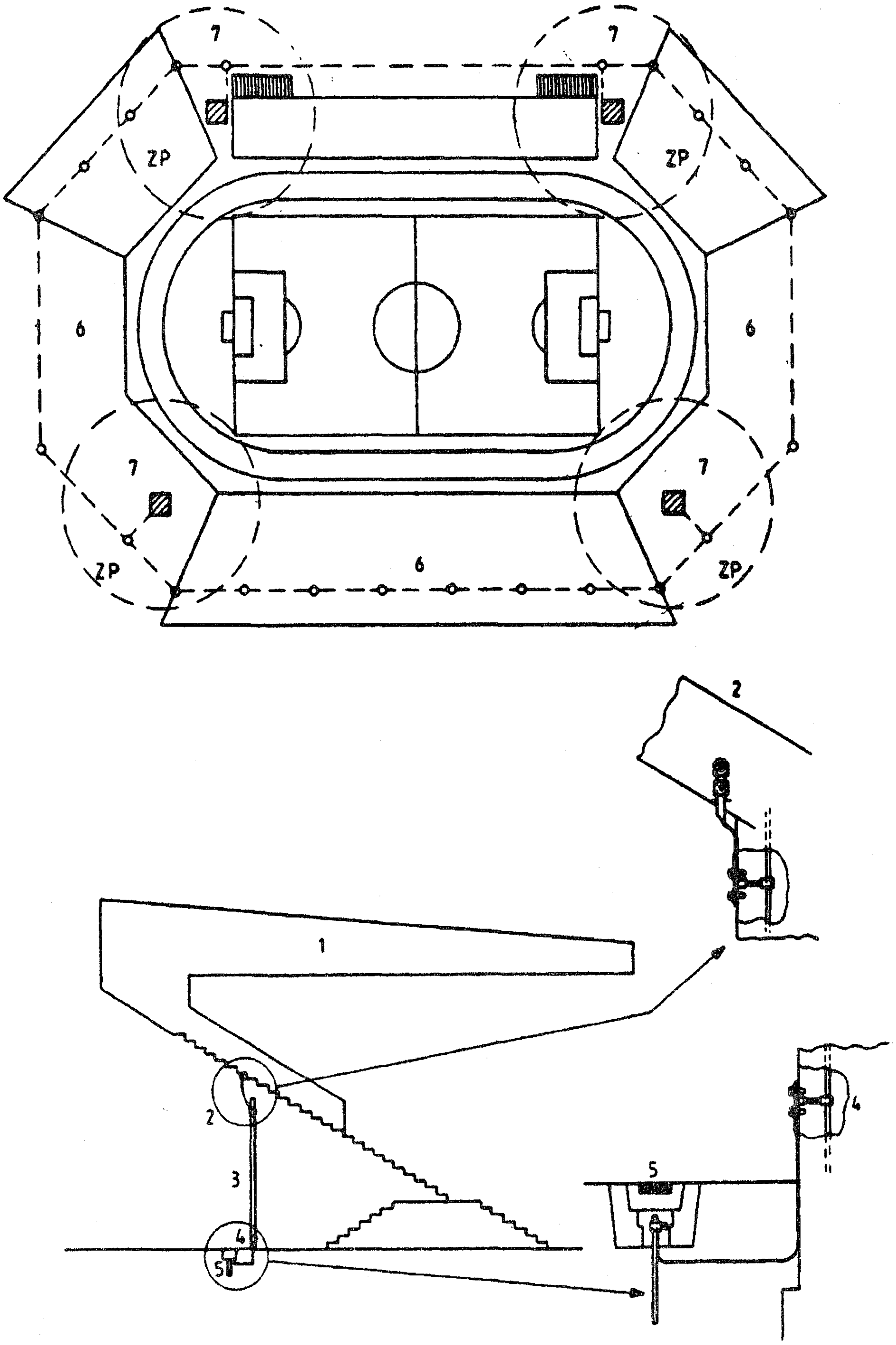
22 CONSTRUCTION SITES

22.1 Structures

Throughout the period of erection of a structure, all large and prominent masses of steelwork, such as steel frameworks, scaffolding, and cranes should be effectively connected to earth. Once work has started on the installation of a lightning protective system, an earth connection should be maintained at all times.

22.2 Overhead Power Lines

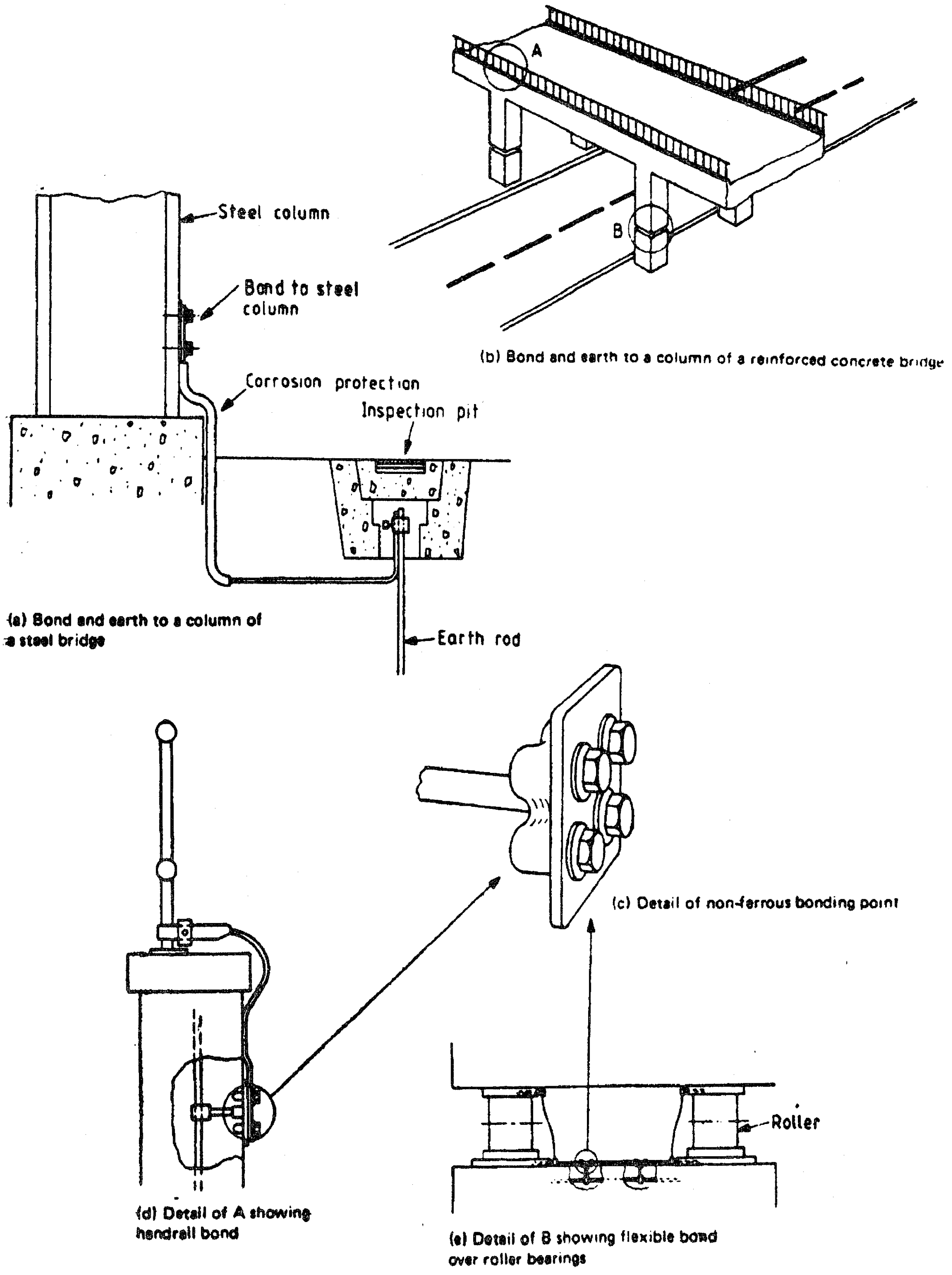
During the construction of overhead power lines, overhead equipment for railway electrification, etc, the danger to persons can be reduced to a minimum by ensuring that an earthing system is installed and properly connected before any



Key

1 Metal roof, providing a natural air termination.
2 Bond to steel roof and reinforcing bar of each concrete column.
3 Reinforcing bars in column, providing natural down conductor.
4 Bond to reinforcing bar for earthing.
5 Earth electrode in concrete housing.
6 Earth ring interconnecting each earth electrode.
NOTE — All continuous or earthed metal should be connected to the earth ring.
7 Light ring column (*see* Fig. 17).

FIG. 37 LIGHTNING PROTECTION SYSTEM FOR SPORTS STADIUM (FOOTBALL GROUND)



(a) Bond and earth to a column of a steel bridge

(b) Bond and earth to a column of a reinforced concrete bridge

(c) Detail of non-ferrous bonding point

(d) Detail of A showing handrail bond

(e) Detail of B showing flexible bond over roller bearings

FIG. 38 BRIDGES

conductors other than earth wires are run out. Once the conductors are run out and insulation installed, they should not be left 'floating' whilst men are working on them, but should be connected to earth in the same manner as when maintenance is being carried out after the line is commissioned.

SECTION 4 MISCELLANEOUS PROVISIONS AND EXPLANATORY NOTES

23 INSPECTION

23.1 All lightning protective systems should be visually inspected by a competent person during installation, after completion and after alteration or extension, in order to verify that they are in accordance with the recommendations in this code. Visual inspections should be repeated at fixed intervals, preferably not exceeding 12 months.

23.2 In addition, the mechanical condition of all conductors, bonds, joints, and earth electrodes (including reference electrodes) should be checked and the observations noted. If, for any reason, such as other site works, it is temporarily not possible to inspect certain parts of the installation, this also should be noted.

24 TESTING

24.1 On the completion of the installation, or any modification to it, the following measurements should be made and the results recorded in a lightning protective system log book:

a) The resistance to earth of the whole installation and of each earth termination.

b) The electrical continuity of all conductors, bonds and joints. Typical examples are illustrated in Fig. 29.

The method of testing shall be that recommended in IS 3043 : 1987.

24.2 If the resistance to earth of a lightning protective system exceeds 10 Ω, the value should be reduced except for structures on rock as described in **18.5**. If the resistance is less than 10 Ω, but significantly higher than the previous reading, the cause should be investigated and any necessary remedial action taken.

Tests should be repeated at fixed intervals, preferably not exceeding 12 months.

NOTES

1 It may be advantageous to choose a period slightly shorter than 12 months in order to vary the season in which tests are made.

2 It is emphasized that before isolating a lightning protection earth, it should be tested to ensure that it is not 'live', using a sensitive voltage testing device.

25 RECORDS

25.1 The following records should be kept on site or by the person responsible for the upkeep of the installation:

a) Scale drawings showing the nature, dimensions, materials, and position of all component parts of the lightning protective system.

b) The nature of the soil and any special earthing arrangements.

c) The type and position of the earth electrodes, including 'reference electrodes'.

d) The test conditions and results obtained (*see* **24**).

e) Any alterations, additions, or repairs to the system.

f) The name of the person responsible for the installation or its upkeep.

26 MAINTENANCE AND UPKEEP

26.1 The periodic inspections and tests recommended in **23** and **24** will show what maintenance, if any, is needed. Particular attention should be given to:

a) earthing;

b) evidence of corrosion or conditions likely to lead to corrosion; and

c) alterations and additions to the structure which may affect the lightning protective system (for example, changes in the use of a building, the installation of crane tracks, erection of radio and television aerials).

27 EXPLANATORY NOTES ON SOME OF THE RECOMMENDATIONS OF THIS CODE

27.1 Clauses 12.3 'Earth Terminations' and 12.4 'Earth Electrodes'

27.1.1 *General*

Comprehensive information on the subject of earthing is to be found in IS 3043 : 1987.

27.1.2 *Effect on Side Flashing and Potential Difference Close to the Earth Electrode*

As outlined in **5.1**, the resistance of the earth termination affects the risk of side flashing within the structure to be protected and the risk of a dangerous potential gradient in the ground adjacent to the earth termination. The risk of side flashing in some types of structure depends on other factors in addition to the resistance of the earth termination and this aspect is discussed in **5.2**. The potential gradient around the earth termination is exclusively a function of the soil resistivity. In Fig. 17 a lightning stroke is assumed to occur to the lightning protective system of a structure. As the lightning current is discharged through the earth electrode, the surrounding soil is raised for the duration of the discharge to a potential with respect to the body of the earth. The resulting potential gradient is illustrated and it is shown how its voltage gradient can be reduced by adding ring earth electrodes to lower the effective earth resistance.

Such a potential difference may be lethal to a person if it exceeds a few thousand volts and to an animal if it exceeds a few hundred volts. As this potential difference is a function of the product of the lightning current and the resistance of the earth electrode, the importance of keeping the latter as low as possible is evident. For practical purposes, a maximum value of 10 Ω is recommended. The danger to persons within a structure is effectively reduced by the presence of any floor other than one of earth or rock.

27.1.3 *Use of Service Pipes as Terminations*

With the growing use of insulated sections between the main service pipes and the feeds entering structures, reliance cannot be placed on their use as either primary or secondary earthing terminations.

All that can be said is that they should be bonded to the lightning protective system internally in such a way that all connections can be inspected easily.

27.1.4 *Lengths of Driven Electrodes*

No limit need be set on the minimum length of a driven electrode; a 1·2 m long electrode may be adequate in favourable soil conditions, particularly where there is a shallow layer of low resistivity soil, such as clay, overlying gravel, sand or rock. Deeply driven electrodes are used where, for example, clay lies beneath gravel. Reliance should not be placed on standing water levels. The water, especially in gravel, may be pure and will not necessarily provide a low resistance value for the electrodes entering into it.

No appreciable advantage in resistance reduction is gained by increasing the diameter or surface area of the driven electrode. Larger sizes become more difficult to drive and are more expensive in materials. For example, for electrodes of 1·2 m in length, the relation between diameter and mass is shown below:

Electrode Diameter	*Approximate Mass*
mm	kg
13	1·4
16	2·3
19	3·2
25	5·4

Thus, the mass of a 1·2 m × 25 mm rod is four times that of a 1·2 m × 13 mm rod.

For the same mass of material, one 4·8 m × 13 mm electrode rod or four 1·2 m × 13 mm electrodes spaced 1·2 m apart will provide a resistance value of about one-third of that of one 1·2 m × 25 mm electrode rod in the same kind of soil.

27.1.5 *Special Cases*

Special considerations apply at earth terminations for:

a) fences containing metal (**16.3.1**),
b) trees (**17**),
c) farm buildings (**20.4**), and
d) structures on bare rock.

If a structure on bare rock is protected as recommended in **12.3.5** and any metal in or on the structure is bonded to the lightning protective system as recommended in **18.5.3**, adequate protection should be provided for persons inside the structure. However, persons leaving or entering such a structure whilst an overhead thunderstorm is in progress are exposed to the risk arising from the high potential drop likely to occur outside during a discharge to the structure.

If surface soil or a rock vein of high conductivity is available within 30 to 50 m from the structure, an earthing electrode as described in **12.4** should be provided and this should be connected to the ring conductor. The risk to a person when leaving or entering the structure is thus reduced, although not completely eliminated.

27.2 Clauses 12.5 'Metal in or on a Structure' and 14 'Structures Exceeding 30 m in Height'

27.2.1 *Bonding of Extended Vertical Runs of Metal Whether Connected to Earth or not*

Any extended metal in or on the structure and not connected to the lightning protective system, for example, water pipes, gas pipes, metal-sheaths, electrical installations, etc, which is in conducting connection with earth remains essentially at earth potential during a lightning discharge. Even if an extended vertical metal part is not in contact with earth, a potential difference between it and the lightning protective system is liable to arise although the magnitude of this potential difference will be smaller than if the metal were earthed. If the resulting short-time potential difference between any part of the lightning protective system and any adjacent metal exceeds the electric breakdown strength of the intervening space, be this air, a wall, or any other structural material, a side flash can occur and this can cause physical damage, ignite flammable material, or cause electric shocks to persons or animals.

27.2.2 *Bonding External Vertical Runs of Metal at Each End*

Such bonding has to be effected at both extremities of any extended vertical metal. The metal may then form part of the discharge path but any risk of physical damage or injury is avoided.

27.2.3 *Which Metal Needs Bonding*

Difficulties are liable to arise in deciding which metal parts require bonding and which can be disregarded in this context. No such difficulties should arise with long continuous installations such as metallic service pipes, ducts, lifts, staircases, or long ladders. These can usually be bonded to the lightning protective system without excessive inconvenience or cost. On the other hand, the presence of short isolated pieces of metal such as window frames, which are merely in fortuitous connection with the ground through the raincovered surface of the structure, can be disregarded.

A structure having reinforcement, steelwork, or cladding forming a continuous close metal mesh in the form of internal reinforcement or screen approaches the condition of a Faraday Cage in which any internal metal assumes the same potential as the cage itself. On such a structure, the risk of side flashing is greatly reduced and the rules for bonding can be substantially relaxed. In cases of doubt specialist advice should be sought.

27.2.4 *Dangers of Thin Metal Coverings*

If any part of the outer surface of the structure is covered with a thin metal skin, this metal may, by accident or design, form part of the path of the lightning current as it goes to earth. The current may be caused to leave the metal, either through the metallic path not being continuous or through its cross-sectional area being inadequate to carry the current without melting. In either case, an arc will be formed and this arc entails some risk of fire if easily ignitable materials are present. The recommended clearances to avoid the risk of side flashing are given in **12.5**.

27.2.5 *Inductance of Down Conductors Relative to Height of Structure*

As the height of a structure increases, the resistive voltage drop in the earth termination network assumes progressively less importance as compared with the inductive voltage drop which occurs only along the down conductors.

27.3 Clause 18 'Trees and Structures Near Trees'

This clause gives the circumstances in which it may be advisable to provide protection for trees.

The recommended earth termination network is designed to protect the roots of the tree and to reduce the potential gradient in the event of a lightning discharge to the tree to a safe value within the area bounded by the outer buried strip conductors.

The practice of sheltering under trees during a thunderstorm is dangerous and should be discouraged wherever possible.

When a tree is struck by lightning, a potential gradient develops along its branches, trunk and roots and this may cause a side flash to an adjacent structure as mentioned in 27.

The flashover strength of a tree can be taken as 250 kV/m as compared with the breakdown strength of air of 500 kV/m. These figures form the basis of the recommendation in 17.1(h) as to the minimum safe clearance between a tree and a structure.

If the actual clearance is found to be too small to prevent the occurrence of a side flash to the structure, the latter should be fitted with lightning protection in such a manner that the energy in the side flash is discharged through the protective system without damage to the structure.

If a tree near a structure is itself fitted with a lightning protective system, the structure may thus be adequately protected. No further lightning protection for the structure will then be required, provided the conditions recommended in this Code with respect to the cone of protection and separation are followed.

27.4 Clause 2 'Miscellaneous Structures'

27.4.1 *Small Tents*

For small tents the foregoing recommendations would be expensive. However, in areas of severe thunderstorm activity, and in mountainous regions, campers using small tents are strongly advised to adopt certain precautions. These are listed below (*see* Fig. 39):

a) Protection for small tents can be achieved by the use of one or two telescopic metal poles outside the tent which should be so arranged that the tent lies within the protective angle recommended in 12.2. The foot of each of these metal poles should be connected to an earth spike placed in a direction away from the tent and, wherever possible, driven into a moist piece of ground. In addition, a bare metal wire should be laid on the ground around the tent and connected to the foot of each metal pole.

b) In the case of a metal-frammed tent, the metal, if continuous, will act as the lightning conductor. The frame should be connected to two earthing spikes driven as described above in opposite directions away from the tent.

c) In a thunderstorm it is essential, particularly in unprotected tents, to avoid the risk of potential difference across the body, This may be accomplished by lying on a metal-frammed cot. If this is not possible, the risk can be reduced by sitting on the ground with the knees down up to the chest and by avoiding physical contact with the tent and with other occupants.

27.4.2 *Sports Stadiums*

When a tall lighting column is struck by lightning, the current flows into the ground from the base of the column and a good approximation to the ground stress can be obtained from an assumption that the equipotentials in the ground are hemispherical shells. Hence with a median current of 30 kA and an average soil resistivity of 103 Ω m the ground stress will be about 50 kV/m at a distance of 10 m from the column and will fall off as the square of the distance (*see* Fig. 17 and 37).

On the assumption that for human beings the voltage gradient should not exceed 10 kV/m, a distance of 22 m from the column base would be needed in order to reach this level.

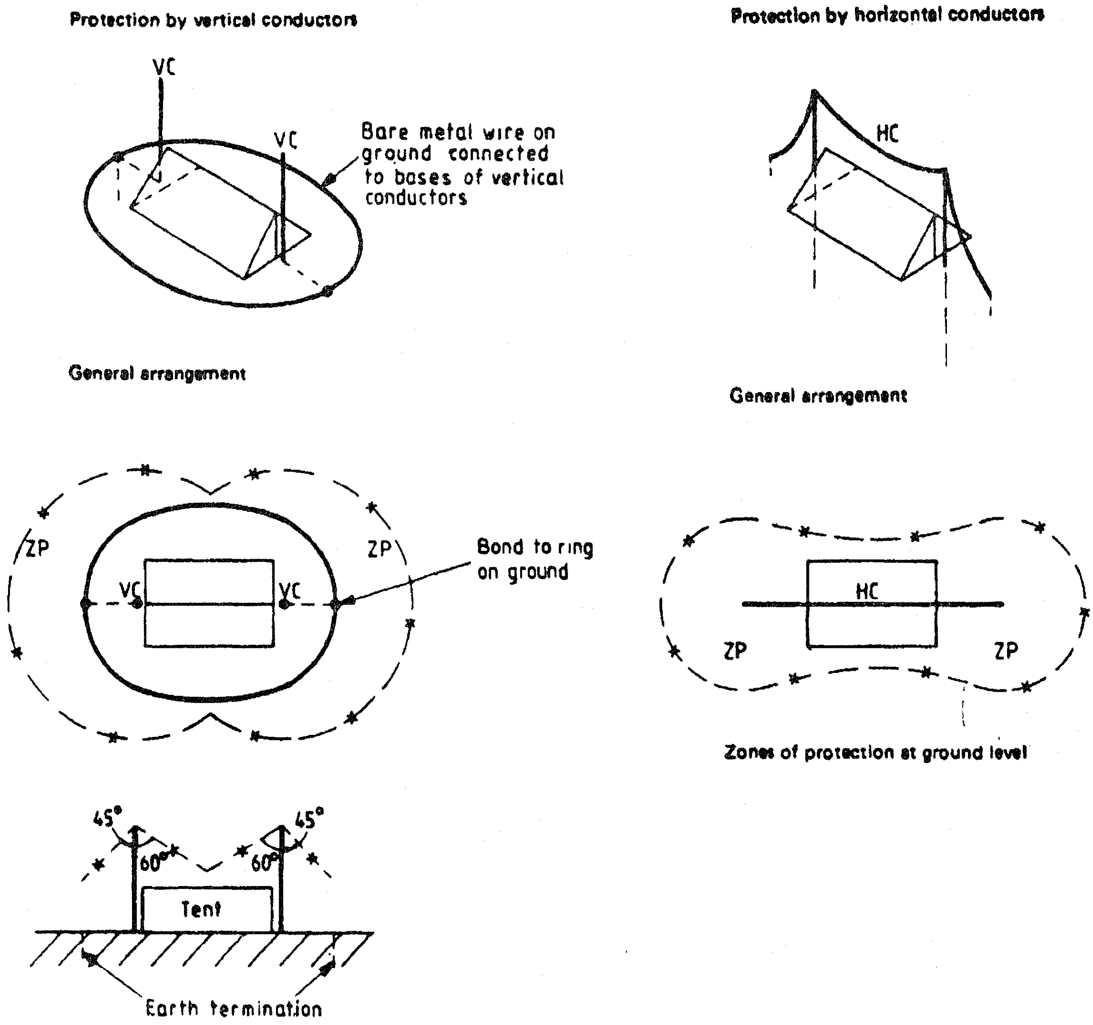
Use of a suitable earth electrode in the form of a circular mesh 10 m in diameter could significantly reduce the ground voltage stress in the vicinity of the tower. Additional protection against ground voltage stress could also be obtained by providing an insulated mat of 4-ply 1 000 gauge PVC sheet just below the final asphalt layer.

For protection against direct contact with the tower itself, a 4 mm coating of epoxy resin sprayed on to the structure from ground level to at least 3 m high is recommended.

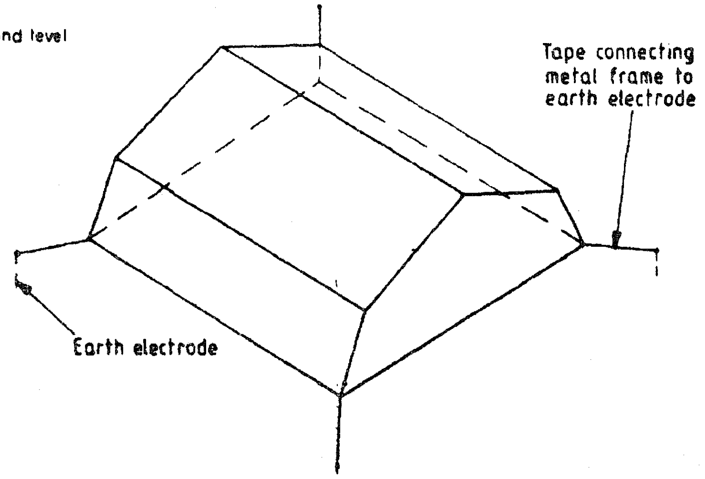
Care must be taken in the choice of material used in order to keep its degradation by sunlight to a minimum.

27.5 Magnetic Wiping of Data in Computer Memories

This question is sometimes asked and although it is possible for data to be wiped from certain types of memories, the current would have to pass so close to the memory store that the chance of it happening can be ignored. No reference to this problem is, therefore, made in this Code.


Protection by vertical conductors
VC
VC
Bare metal wire on ground connected to bases of vertical conductors
General arrangement
Protection by horizontal conductors
HC
General arrangement
ZP
ZP
VC
VC
Bond to ring on ground
HC
ZP
ZP
Zones of protection at ground level
45°
45°
60°
60°
Tent
Earth termination

Zones of protection at ground level
(a) Ridge tents



(b) Frame tents

FIG. 39 LIGHTNING PROTECTION FOR TENTS

ANNEX A

(*Foreword*)

COMPOSITION OF ELECTRICAL INSTALLATIONS SECTIONAL COMMITTEE, ETDC 20

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Secretary
SHRI K. GANESH
Deputy Director (Elec tech), BIS

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ETDC 20 : P9

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(Continued from second cover)

This Code was first issued in 1963 and revised subsequently in 1969. The 1969 version was an attempt to take into account the then advances in the protection of buildings and structures against lightning and brought up to date the first version by incorporating the current practice in providing protection against lightning.

Based on data available, the 1969 version introduced a digital system of assessing the risk of damage to buildings due to lightning. In this system, index figures are allotted to the various factors influencing the risk of damage due to lightning to buildings and structures. The degree of necessity or otherwise of lightning protection can be judged from the sum of the index figures — the higher, the total figure, the greater the need for lightning protection. It was, however, emphasized that this system should be regarded as an aid to judgement and not as a sole criterion.

The present revision updates the contents of the Code and also reorganizes the presentation in such a manner as to enhance its use. While retaining most of the topics, it includes additional factors and changes, particularly the current waveform which affects the clearance for preventing side flashing.

This Code is intended to give guidance on the principles and practice which experience has shown to be important in protecting structures against damage from lightning. This Code is not a specification, but gives recommendations and guidance. This limitation is due to the inconsistent nature of the lightning phenomenon which means that the degree of protection has to be based on statistics and cannot be stated in exact terms. Moreover, the Code recognizes the fact that wide variations in the architecture of the buildings and in the topography and atmospheric conditions in different parts of the country require that considerable freedom in the design of the protective system should be given.

In the preparation of this Code, assistance has been derived from BS 6651 : 1985 'Code of Practice for Protection of Structures Against Lightning', issued by the British Standards Institution.

Composition of Electrical Installations Sectional Committee, ETDC 20, which was responsible for the preparation of this standard is given in Annex A.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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